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STUDY OF LARGE LAUNCH VEHICLES UTILIZING SOLID PROPELLANTS

FINAL REPORT
VOLUME II

Submitted to

George C. Marshall Space Flight Center

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10 February 1962

THE BOEING COMPANY
AERO-SPACE DIVISION
SEATTLE, WASHINGTON

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Annex #1
George C Marshall SFC
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Moog Servocontrols, Inc.

This assistance, in the nature of review and corroboration of the principal aspects of the design and development of the large solid motors suggested in this report, is gratefully adknowledged.

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I. ABSTRACT

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The purposes of this report are:

1) To present two-stage vehicle configurations using solid rockets in the first stage to boost a family of payloads ranging from 30,000 to 350,000 pounds to a 307-nautical-mile orbit. (Vehicles shown use LO_2/LH_2 upper stages and can be compared to the Saturn C-1, C-3, C-4, and the Nova vehicles);

2) To define the methodology used to establish these vehicle configurations;

3) To describe the ground systems and facilities required to support these vehicles;

4) To provide the estimated program development time required for the vehicles.

II. INTRODUCTION

This study of large launch vehicles utilizing solid propellants was initiated to establish the important system parameters and operational problems associated with such vehicles. The study was conducted in three phases.

Phase I, as covered by Volume I of this document, included a study of both two- and three-stage vehicles for payloads of 50,000, 100,000, and 350,000 pounds delivered to a 307-nautical-mile orbit. All vehicles consisted of a single LO_2/ LH_2 upper stage combined with one or two solid stages. Maximum effort was made to collate and use data from the previous liquid-solid vehicle studies conducted by members of the solid-rocket industry. The product of the Phase I study was a family of 22 vehicle configurations with a brief survey of the related development and operational problems. Attention was given to the relative effects of such solid-rocket concept variations as single unitized motors, clustered solid motors, and clustered segmented motors. A preference, based on availability and assumed technical risk, was established for the segmented-solid-motor concept. Effort made to determine some of the limiting factors on stage ratio resulted in a selection of 1.6 as the maximum thrust-to-weight ratio for the first stage that can be used without exceeding a dynamic pressure of 1200 psf.

Phase II study covered the configuration and evaluation of a more select group of vehicles. Four basic vehicles, corresponding to the Saturn C-1, C-3, C-4, and the Nova, were selected. An additional two vehicles were added to this group; the first was a variation in the C-3 type vehicle to explore the effects of segmented versus unitized solid motors in the first stage and the second was a laterally staged version of the C-4 type vehicle to evaluate the effect of this variation. A further ground rule established the second-stage requirement for a single J-2 engine for the C-1 type vehicle, four J-2 engines for the C-3 and C-4 type vehicles, and a choice of three or four Y-1 engines for the Nova-type vehicle. The payload for the C-1 type vehicle was established as 30,000 pounds and the payloads for the C-3, C-4, and Nova-type vehicles were maintained as 100,000, 180,000, and 350,000 pounds, respectively, for a 307-nautical-mile orbit. The Phase II study covers the technical approach used in establishing these vehicles as well as study of the operational problems and ground support facilities.

The Phase III portion of this study, as reported in Volume III, emphasizes the cost and funding aspects of the vehicles configurated during the Phase II study. The cost per pound of payload in orbit for each configuration is shown with a breakdown of both direct and indirect system costs. A proposed fiscal-year expenditure plan is also presented.

The framework for an integrated study of large launch vehicles was provided by establishing a number of baseline concepts at the start of each phase of the study. These baseline concepts were used as tools to establish the important system parameters and operational problems of large launch vehicles employing solid-propellant motors in conformity with the contract work statement. The baseline concepts were not optimized or integrated with each other as they were not intended as suggested approaches but rather as feasible approaches by which specific tasks might be achieved.

For example, during Phase I study, on-pad casting of large unitized solid motors was assumed. A conclusion of the Phase I study was that on-pad casting of large unitized motors is undesirable in terms of launch-pad occupancy time, and, therefore, in terms of launch-base land and facility requirements. This conclusion was later reflected in the Phase II study by the use of off-pad casting, a water-borne motor-handling concept, and a vehicle assembly complex utilizing a separate vehicle first-stage assembly site for large unitized motors. Again, this concept was not optimized or integrated with other baseline concepts, but was used as a tool to establish parameters and define problems.

III. SUMMARY AND CONCLUSIONS

THRUST-TO-WEIGHT RATIO

For all vehicles of the Phase II study except the 180,000-pound payload vehicle, the first stage was sized to have a minimum launch weight resulting in second-stage thrust-to-weight ratios between 0.85 and 1.18. To the extent possible, this was done on the 180,000-pound payload vehicle without reducing the second-stage thrust-to-weight ratio to an undesirable value below 0.85. The launch weight of the 180,000-pound vehicle could be reduced significantly by increasing the number of J-2 engines. The first-stage thrust-to-weight ratios were maintained between 1.5 and 1.6 to minimize launch weight and remain within the dynamic pressure limits.

THRUST TERMINATION

The study showed that, even for dynamic pressures as high as 1200 psf, thrust termination was not required for the solid motors of the study vehicles in order to provide an acceptable net acceleration between the booster and an assumed Apollo-type escape capsule. The margin of safety was small enough, however, to necessitate review as soon as the escape system is defined further.

SOLID MOTOR OPTIMIZATION

The performance optimization of solid-motor chamber pressure and expansion ratio can reduce vehicle launch weight by as much as five percent for the vehicles studied. The chamber pressure optimization depends on the ratio of inert stage weights <u>dependent</u> upon chamber pressure to those inert weights <u>independent</u> of chamber pressure; when the ratio goes up the optimum pressure goes down. For example, the 100,000-pound payload vehicle, using unitized motors, has an optimum chamber pressure occurring at only 450 psia. This effect will result in higher optimum chamber pressure as motor length-to-diameter ratio is increased or as segmentation is incorporated in motor design. Expansion cones as large as possible, without compromising vehicle design, are indicated. A more detailed study, including a cost analysis, is required for confirmation.

DYNAMIC PRESSURE

Significant reductions of dynamic pressure can be attained by replacing constant sea-level thrust in the solid stage with regressive or regressive-progressive thrust programing. A 16-percent reduction in maximum dynamic pressure was obtained by using a 2.2 initial thrust-to-weight ratio. This was lowered to 1.4 during the first third of the first-stage burn time, and then increased during the last two-thirds of the burn time to 1.7 at first stage burnout, using the 30,000-pound payload vehicle. Thrust programing of solid motors, which can be realized by design parameters such as motor thrust programing through grain design, should be explored and analyzed on the basis of payload delivery costs.

STAGING

Staging of solid-liquid launch vehicles requires careful consideration of solid motor thrust decay, particularly with clustered boosters. Canting of clustered motor nozzle axes through the vehicle center of gravity reduces control requirements for the vehicle during first-stage burnout. Vehicle stability and control during solid-stage burnout can be provided by stabilizing the vehicle with fins or auxiliary stabilization systems. A degree of vehicle instability can be allowed if the tail-off time is kept low. For the vehicles of this study, thrust decay time is effectively reduced by igniting booster retrorockets prior to stage burnout. The retrorockets are sized to provide a 0.5-g deceleration of the booster, as required by S-II specifications. In addition, they cancel low levels of thrust at termination of the stage thrust tail-off. By providing a 1.0-g deceleration force in the retrorockets, both stage deceleration and thrust cancellation can be achieved several seconds before stage burnout. Sizing of retrorockets will become more definitive when thrust decay characteristics of large solid motors become available.

VEHICLE STABILITY

The vehicle configurations have been provided with enough inherent stability to meet a crew escape criterion of time-to-double-amplitude of two seconds at maximum dynamic pressure. The time-to-double-amplitude is defined as the time which is required for an initial angle of attack to double in magnitude due to uncontrolled aerodynamic divergence. This stability criterion is based on a minimum allowance for crew reaction time with the autopilot failed. Because the important parameter is sufficient time for crew decision, a criterion of vehicle uncontrolled divergence rate is used rather than a stability margin.

UNITIZED VERSUS SEGMENTED MOTORS

Performance characteristics between the star grain proposed for unitized motors and the cylindrical grain proposed for the segmented motors are very comparable with no outstanding advantages shown for either. The weight of joints and insulation of the segmented motor results in a slightly lower motor mass fraction than for a unitized motor. However, the circular port of the segmented grain gives rise to less stress concentration and the transverse cuts relieve axial stress.

IGNITION OF SOLID MOTORS

Ignition of clustered motors should be accomplished by a launch-pad-retained system that will allow adequate redundancy to be incorporated to ensure the required reliability. The launch-pad-retained system will not penalize the vehicle by adding the weight and complexity required to ensure this reliability.

STRUCTURAL COUPLING

Coupling between pitch control frequency and vehicle first-mode bending frequency requires careful attention. The first-mode body-bending frequency should be greater than five times the design controlled-pitch frequency. The high solid-booster density influences the vehicle mass distribution in a manner that reduces the vehicle first-mode bending frequency. This mass distribution effect of the solid motors is not experienced with comparable all-liquid systems. The vehicle first-mode bending frequency is not greatly effected by variations in the first-stage stiffness. A lower vehicle-fineness ratio, lower pitch-control frequency, and/or increased vehicle stiffness should be incorporated to reduce structural coupling effects.

THRUST VECTORING

Effort is currently being directed in the industry to develop the liquid injection system of thrust-vector control, which was chosen for the vehicles configurated. However, further study and analysis are needed to establish detailed control system requirements, to analyze and test all feasible thrust-vector control systems, and to recommend selections.

CLUSTERING STRUCTURE

The clustering structure found to be the most satisfactory for the four solid-motor tandem staged vehicles of this study was one in which the forward end was fixed and allowance was made for expansion at the aft end. To provide the fixed forward end, barrel section extensions of the forward skirts are tied together by truss panels. Further study, testing, and detail design are needed to determine the optimum cluster structure method which will provide maximum rigidity with minimum weight and complexity.

LATERAL STAGING

Lateral staging did not disclose significant advantages over tandem staging, within the limited study given this variation. Total launch weight was higher for the lateral staged vehicle, due to a decrease in second-stage mass fraction. Further study will be required to determine the optimum structural concept and to explore the possible advantages of the inherent increased vehicle stiffness.

SEGMENTED MOTOR RIGIDITY

Mechanical tolerances in the joints of segmented motor cases will not contribute to vehicle flexibility; this is characteristic of mechanical joint designs normally used in primary airborne structures. The segmented joint reinforces the case wall. Operating chamber pressures are sufficient to maintain tension loads in the joints under any external loading condition. For example, the most severe flight-loading condition for the vehicles studied resulted in a new axial tension in the case wall of about 20 percent less than that imposed by the internal chamber pressure. The vertical-shear forces introduced in the cases were approximately

1/20 of the magnitude required to produce relative displacement of the joint interfaces.

MOTOR CASE MATERIAL

The choice of a low alloy, high-strength steel, heat treated to an ultimate strength of the order of 200,000 psi, was made in accordance with state-of-the-art design procedure. Because of the thickness requirements in the subject applications, they will be in the brittle fracture range, and high rejection rates are a probability.

In spite of a relatively high material cost, titanium also should be evaluated further. An annealed and as-welded titanium alloy case material would eliminate the heat treat requirement and provide good fracture toughness while retaining competitive case weight and stiffness properties. The absence of adequate design data for this material in large motor case applications defers its present use.

Although the high-strength aluminum alloys possess good stiffness characteristics, the thicknesses required introduce the disadvantages of plane strain or brittle fracture, as with the high-strength steels, and in addition, result in greater case weight.

The high-nickle-alloy steels are promising for applications of this type, in that good fracture toughness is indicated at ultimate material strengths approaching 300,000 psi. Certain fabrication problems with this material remain to be evaluated.

PROPELLANT FACILITIES

Additional propellant mixing facilities will be required to meet the launch rates investigated by this study with the possible exception of the 30,000-pound payload vehicle. New facilities for mixing and casting large unitized motors should be located on or near a navigable waterway to minimize handling and transportation.

SOLID MOTOR CASE FACILITIES

The solid motor cases can be produced with present facilities, with moderate increase in heat-treat facility capacities. However, the initial fabrication of large unitized motor cases should be done by welding together heat-treated segments. Anticipated development of large spin-forge machines and techniques, to locally heat-treat welded joints, should improve case fabrication quality significantly within 3 years.

DEVELOPMENT TIME

Although development time for segmented motors is less than for unitized motors, the first-flight airframe and electric and electronic ground support equipment availability are critical phasing items. However, PFRT testing will also become a critical phasing item for unitized solid motors.

RELIABILITY

No significant variation between the segmented and the unitized solid motor reliability could be determined. However, the solid motor stage first-unit reliability will be high for the vehicles investigated in this study. Second-stage reliability predictions indicate the need for improvements, such as the addition of redundant features, in order to achieve acceptable first-unit reliabilities. Engine-out capability in the second stage would increase reliability to an acceptable level on the multiple engine configurations studied. The single-engine 30,000-pound payload vehicle will have an adequate reliability without redundant features.

SYSTEM TEST

An "all up" test configuration (where all stages are functioning) from the start is recommended for all flight tests, to minimize development time and cost. A total of six successful flight tests (four booster and two escape) are required for all of the vehicles in the study. With a minimum acceptable first-unit vehicle reliability, a total of ten vehicles of the Nova type or nine vehicles of the remaining configurations must be provided to complete the required flight tests.

ACOUSTICAL LEVELS

Acoustical levels will determine launch-base boundaries. All land areas within a noise level of 125 db or over (5700 to 19,800 feet from launch stand for vehicles studied) must be under control of the governing agency. Spacing of vehicle hazardous facilities including the final vehicle assembly area and the solid-motor static-test facility, relative to each other and nonhazardous facilities, must be based on the assumption that loaded solid motors are class-nine explosives. However, subsequent explosive hazard testing of the motors should establish a class-two (fire hazard only) rating for them.

IV. VEHICLE DESIGN AND DEVELOPMENT

A. GENERAL DESIGN CONSIDERATIONS

Selected for the Phase II study were six launch vehicles in the Saturn-Nova class with payloads of 30,000, 100,000, 180,000, and 350,000 pounds and solid-motor first stages. A brief preliminary design of the vehicles established the general design concepts to be incorporated into these vehicles and identified problems associated with their development and operation.

Vehicle trajectories were based on dynamic pressure and acceleration limits, payload mission and stage specific impulse and propellant mass fraction. Propulsion capabilities of the solid motors were based on state-of-the-art data, evaluation of large-solid-motor studies, and the direct assistance of several solid-motor manufacturers. Structural aspects considered include vehicle interstage and booster-clustering concept, acoustic noise level and frequency, ground and flight loads, aerodynamic heating, and vehicle frequencies. Vehicle aerodynamic-stability and boost-control characteristics have been indicated.

A short development time was emphasized on the 30,000-pound-payload vehicle, resulting in the use of a segmented-motor first stage. One 160-inch-diameter motor is used for the first stage on the basis of improved vehicle-control characteristics and vehicle reliability over clustered 120-inch-diameter motors.

Two launch vehicles were studied for the 100,000-pound payload; only the solid-booster stages differed for these vehicles. One of the boosters used 160-inch-diameter unitized motors while the other used 160-inch-diameter segmented motors. The two booster concepts were chosen to provide a comparative study of the two solid-motor designs. Four solid motors were used in the booster stage as the best approach to vehicle growth that would accommodate a 180,000-pound payload using four J-2 engines in the second stage of both the 100,000- and 180,000-pound-payload vehicles.

The 180,000-pound-payload vehicle uses four 160-inch-diameter solid motors in the first stage. A second 180,000-pound-payload vehicle uses six solid motors in the first stage and employs lateral staging. The laterally staged booster was designed for staging all six motors simultaneously; time did not permit evaluation of multiple staging for the solid motors. The laterally staged vehicle was dropped from a detailed study when it appeared that the laterally staged vehicle would be heavier than the tandem-staged vehicle and time did not permit an adequate study of staging concepts for the vehicle.

The 350,000-pound-payload vehicle consisted of a first stage containing four motors, each 16 feet in diameter, and a second stage with three Y-1 engines. While it is felt that solid motors having diameters in excess of 14 feet represent some technical risk, the reduction in number of motors in the first-stage cluster was believed to compensate for the risk.

1. PERFORMANCE

INTRODUCTION AND GROUND RULES

The object of the Phase II performance study was to optimize specific two-stage solid-liquid vehicles with payload capabilities of 30,000, 100,000, 180,000, and 350,000 pounds. The following ground rules retained from the Phase I study were employed in the performance analysis:

1) Mission: 307-nautical-mile circular orbit, easterly launch from the Atlantic Missile Range.
2) Dynamic pressure limits of 400 psf at staging and 1200 psf maximum.
3) Maximum acceleration limit of 8 g's.
4) 1st stage I_{sp} = 240 seconds (sea level), $\epsilon = 8, P_c = 800$ psi.
5) 2nd stage I_{sp} = 428 seconds (vac), $\epsilon = 27.5$.
6) Payloads include 3-1/2 percent ΔV reserves.
7) Neutral burning in first stage.

PRELIMINARY VEHICLE SELECTION

The design limits on first-stage thrust-to-weight ratio (T/W) and burn times as imposed by dynamic pressure and acceleration were determined in Phase I and are shown in Figure IVA1-1. The Phase I ground rules limiting the maximum T/W to values between 1.6 and 1.5 were used for the Phase II studies.

The preliminary performance evaluations of the Phase II study consisted of determining, for a given payload and second-stage thrust, a vehicle launch weight as a function of second-stage propellant weight. These trade studies are shown in Figures IVA1-2 and IVA1-3 for the payloads of interest. The initial T/W ratio for all vehicles was assumed to be 1.60 and the first- and second-stage mass

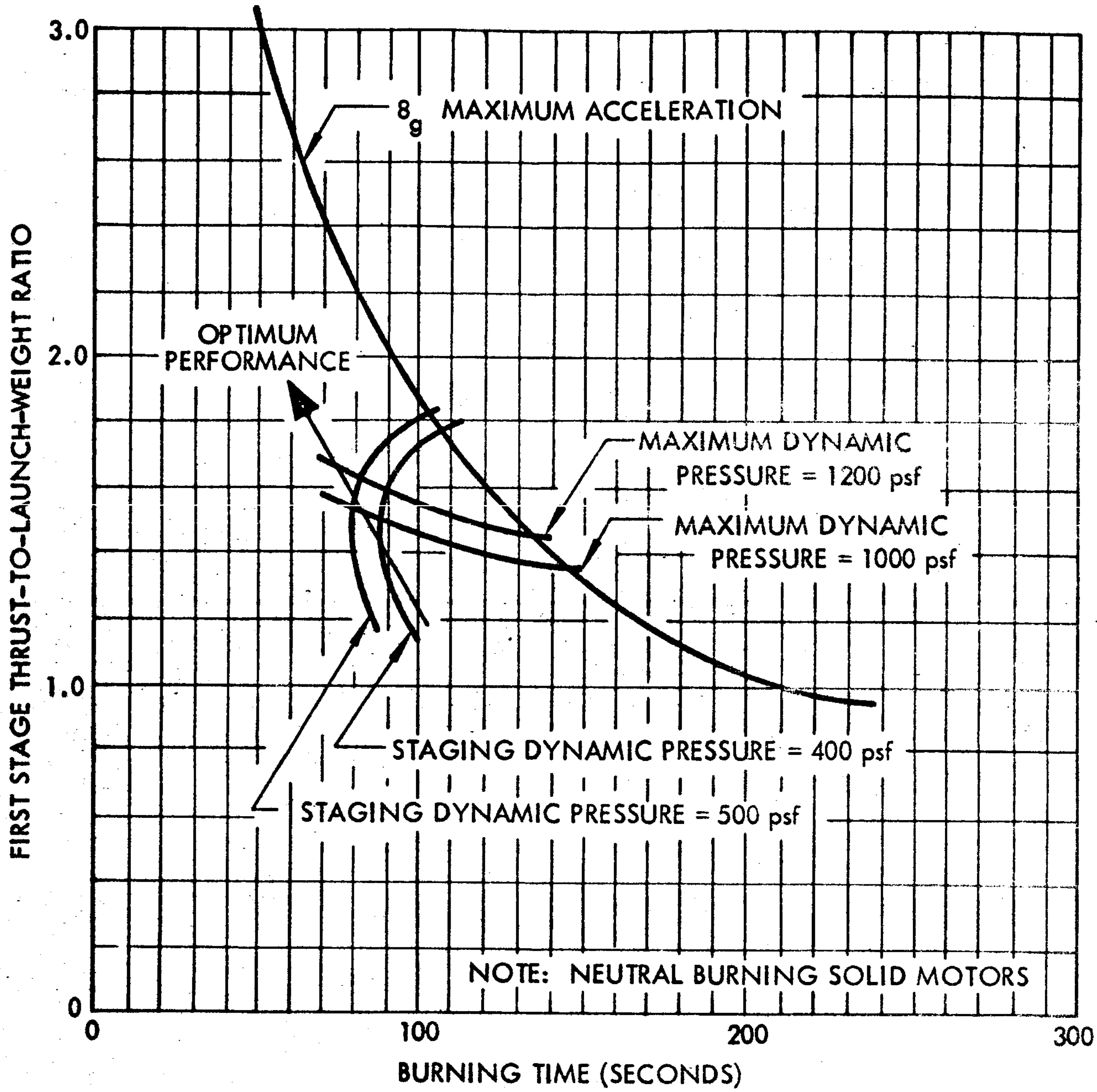


Fig. IV A1-1 SUMMARY OF DESIGN LIMITS

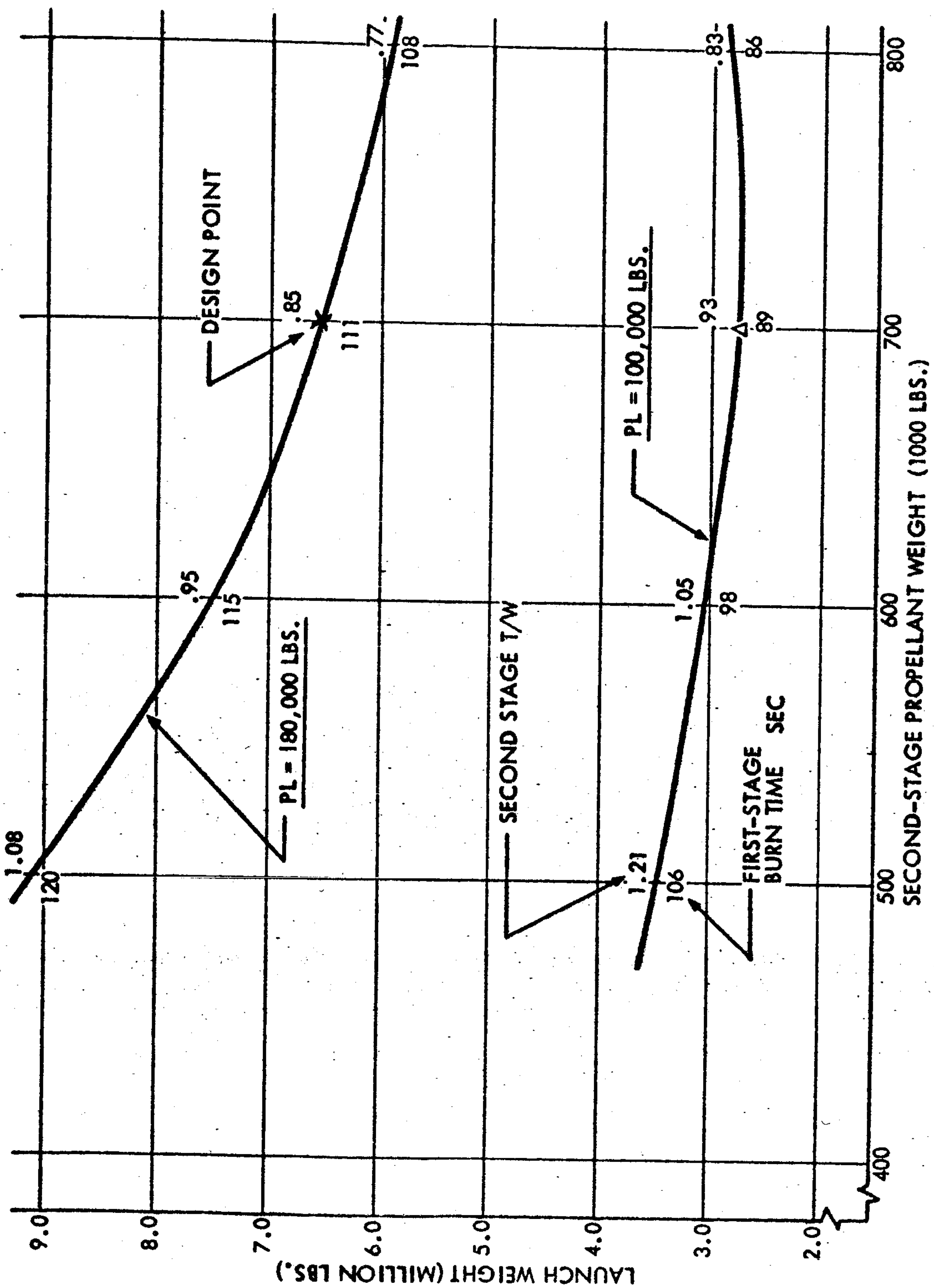


Fig. IV A1-2 PRELIMINARY VEHICLE SELECTION

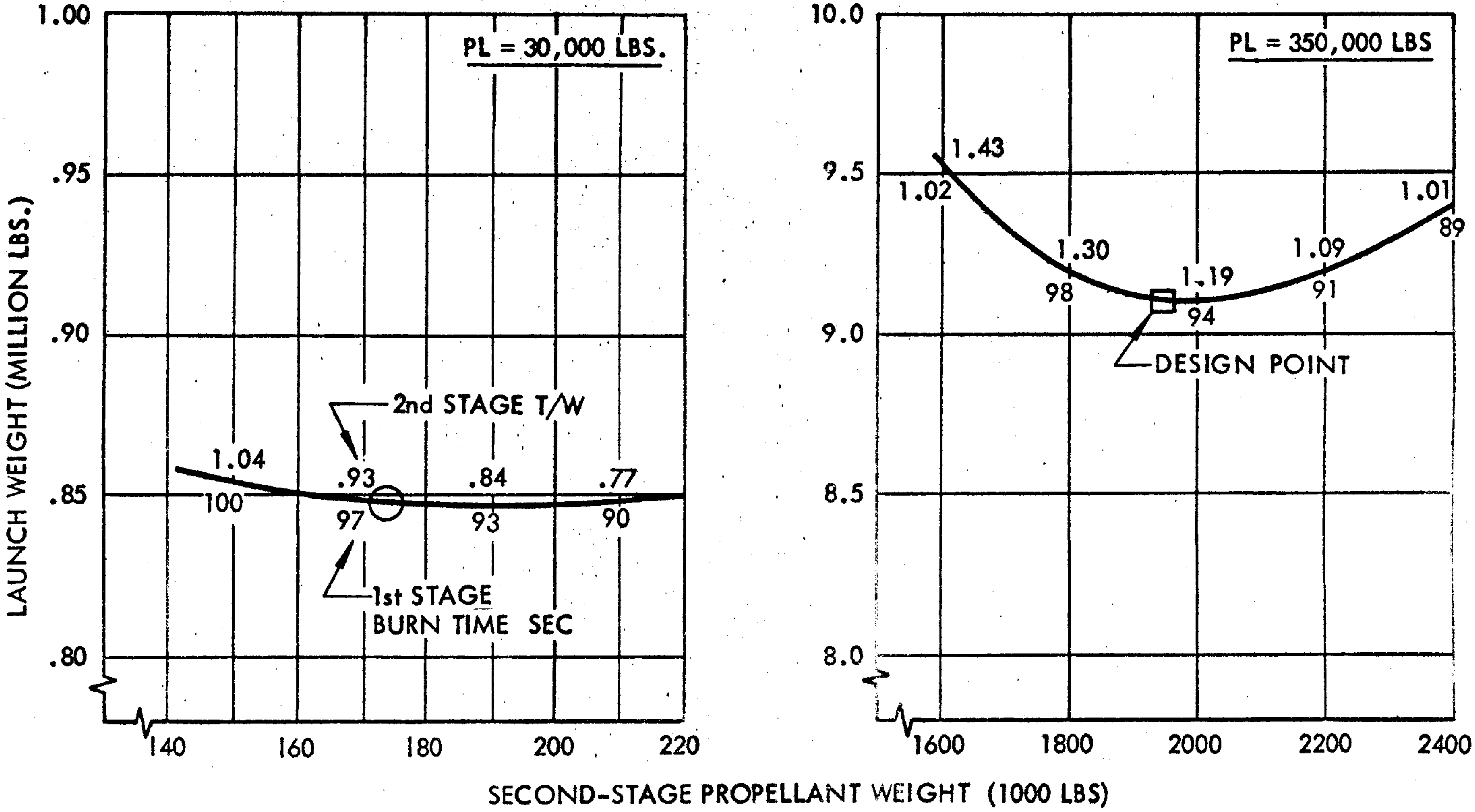


Fig. IV A1-3 PRELIMINARY VEHICLE SELECTION propellant fractions (λ') were held constant for these initial trade studies. Because the second-stage thrust was fixed for each payload, the second-stage propellant weight determined the second-stage T/W ratio, the staging velocity, and first-stage burn time.

These trade studies were accomplished using parametric data based on IBM 7090 computer runs. The parametric data included the effects of gravity, drag, and thrust vector losses as well as the effect of a rotating Earth. The computer runs used a trajectory that assumed a vertical launch to 400 fps followed by an instantaneous tilt and gravity turn to first-stage burnout. The second stage was flown at the angle of attack necessary to burn out at an altitude of 350,000 feet and zero flight path angle.

It was assumed that the optimum performance vehicle would have a minimum launch weight for a given payload and second-stage thrust. Therefore, the second-stage propellant weight or staging velocity was varied until a minimum launch weight occurred. However, because the second-stage thrust was fixed, the second-stage propellant weight corresponding to a minimum launch weight resulted in low second-stage T/W ratios. A minimum allowable second-stage T/W ratio of .85 was assumed for this study. For the 180,000 pound payload vehicle, the second-stage T/W ratio reached this minimum level before a minimum launch weight was reached as is shown in Figure IVA1-2. For the other payloads the vehicles had second-stage propellant weights which resulted in minimum launch weights.

A summary of the results of the preliminary performance studies are shown in Figures IVA1-4 and IVA1-5. Figure IVA1-4 shows the effects of designating the second-stage thrust and payload on the first-stage burn time, vehicle launch weight, and second-stage propellant weight. This data is for a fixed first and second stage λ'. The data shows that as the payload per second-stage engine thrust, P.L./T_2, increases, the first-stage burn time and launch weight increase. The Phase I parametric data has shown that the maximum payload-to-

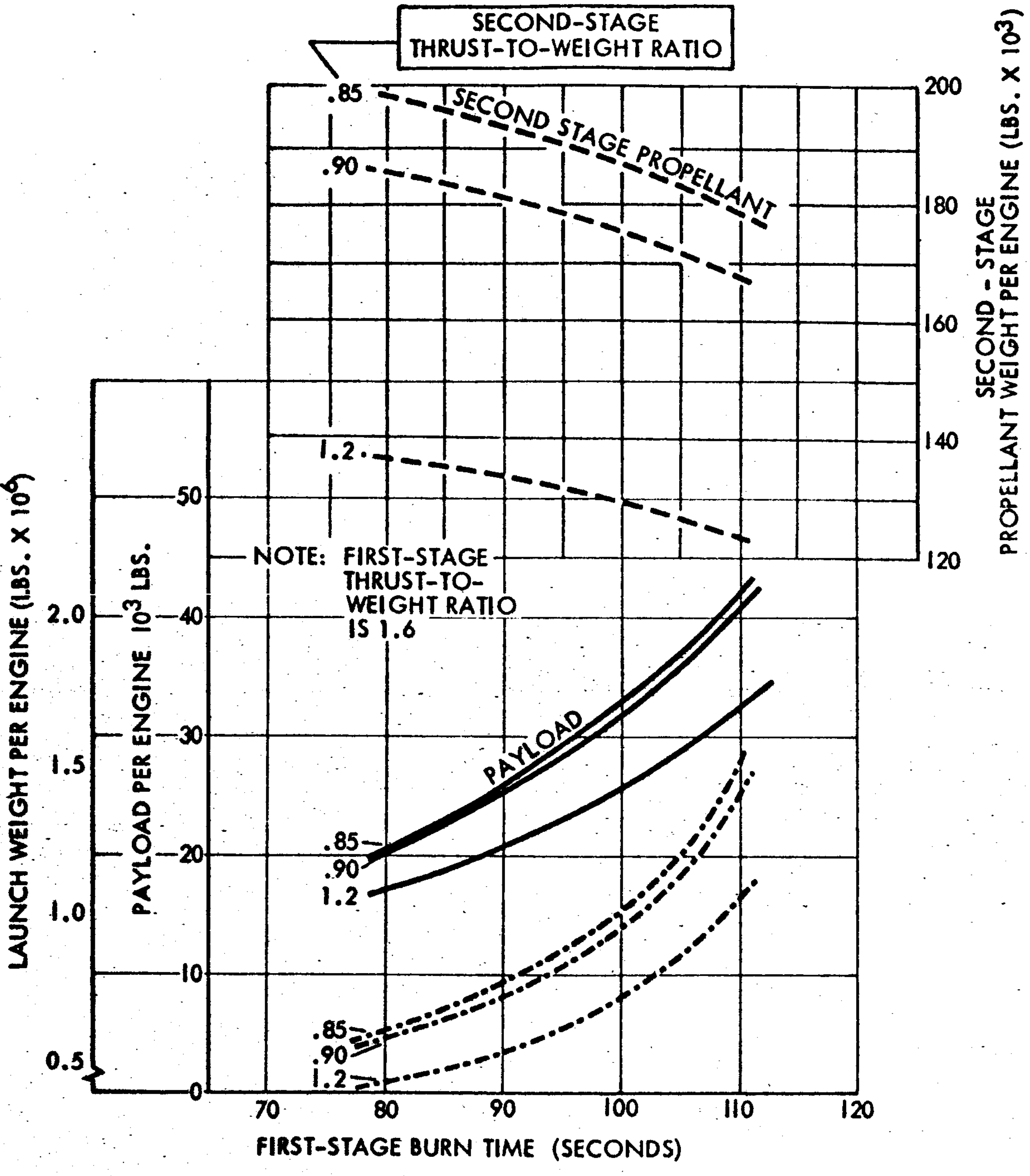


Fig. IV A1-4 PRELIMINARY PERFORMANCE PER UPPER STAGE ENGINE (J-2)
(200,000-LB. THRUST)

PAYLOAD	SECOND STAGE THRUST	PL/T_2
30,000 LBS	200,000 LBS.	.150
100,000 LBS	800,000 LBS	.125
180,000 LBS	800,000 LBS	.225
350,000 LBS	3,000,000 LBS	.116

$T/W_{o1} = 1.6$
$\lambda'_1 = .87$
$\lambda'_2 = .92$
$I_{sp_1} = 240$ SEC (S.L.)
$I_{sp_2} = 428$ SEC (VAC)

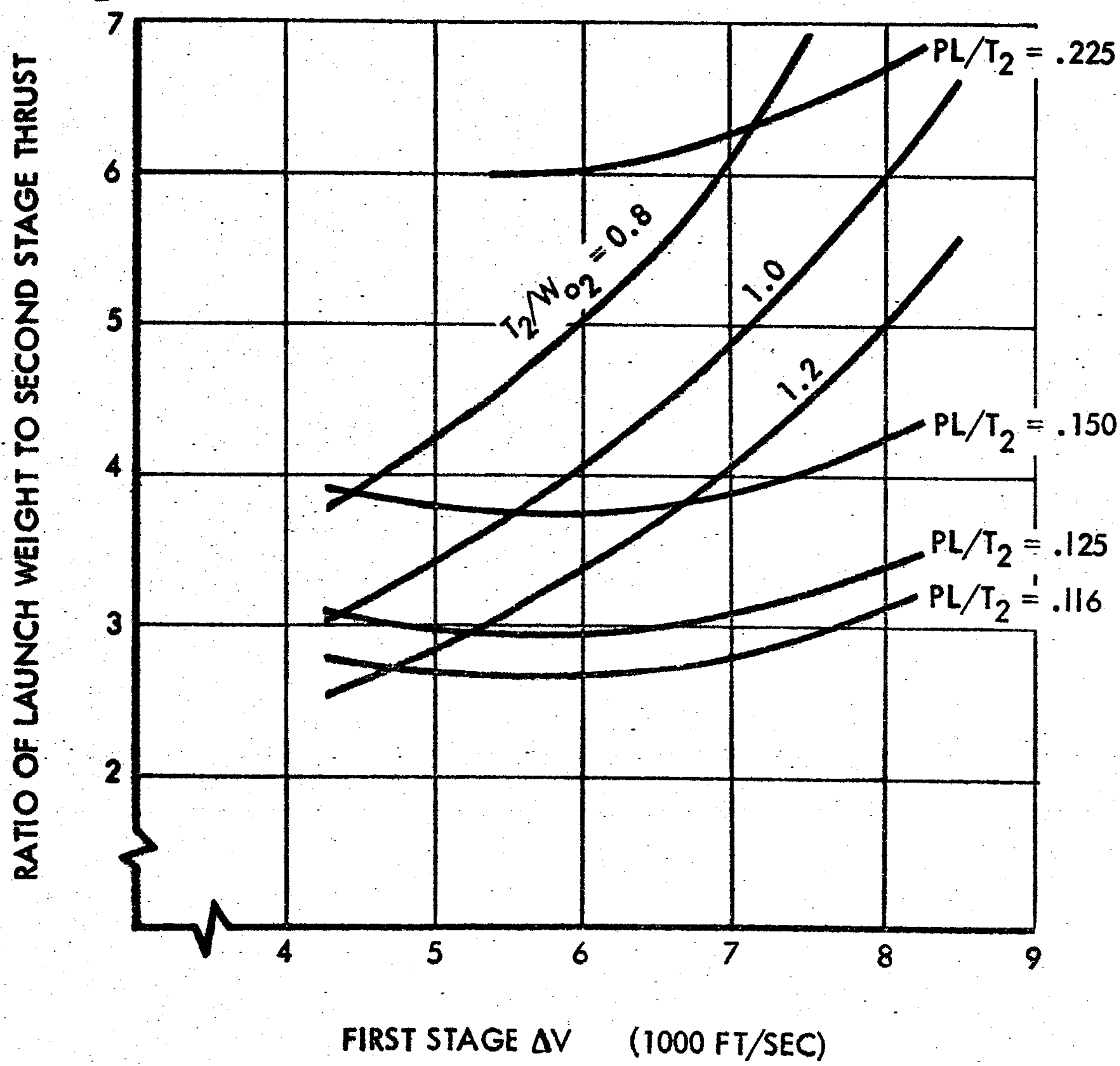


FIG. IV A1-5 PRELIMINARY PERFORMANCE PER UPPER STAGE ENGINE launch weight ratio occurs at burn times between 80 and 90 seconds. However, the P.L./T_2 ratios considered in this study result in payload-to-launch weight ratios which are below optimum values.

Figure IVA1-5 shows the effect of staging velocity on launch weight for various values of payload to second-stage thrust. The data shows that for the range of P.L./T_2 ratios considered in the Phase II study, the optimum staging velocity is between 5000 and 6000 fps. Lines of constant second-stage thrust-to-weight ratios are shown to indicate that for the 180,000 pound payload case (P.L./T_2= .225), the optimum staging velocity cannot be used without going to a very low second-stage thrust-to-weight ratio.

FINAL VEHICLE SELECTION

From the preliminary performance data shown in Figures IVA1-2 and IVA1-3 final design-point vehicles were selected. The second-stage propellant weights of these final vehicles are indicated in Figures IVA1-2 and IVA1-3. A detailed performance analysis of each vehicle was made on the IBM 7090 computer and consisted of finalizing vehicle weights and performance parameters. Trajectory studies were also completed and an optimum trajectory established for each vehicle. Because of these studies, the initial T/W ratio of the 180,000 pound and 350,000 pound payload vehicles were reduced from 1.60 to 1.50 and 1.55, respectively, to meet the maximum dynamic pressure limits specified in the ground rules.

The trajectories of the final vehicles are similar in shape although modified by the different first-stage burn times, as is shown in Figure IVA1-6. The trajectory of the N-UC4 vehicle has a less-pronounced hump because of the higher second-stage T/W ratio. The time histories of dynamic pressures and accelerations for all the vehicles shown in Figure IVA1-7 are quite similar. The maximum and staging dynamic pressures and maximum accelerations are within the limits established by the ground rules.

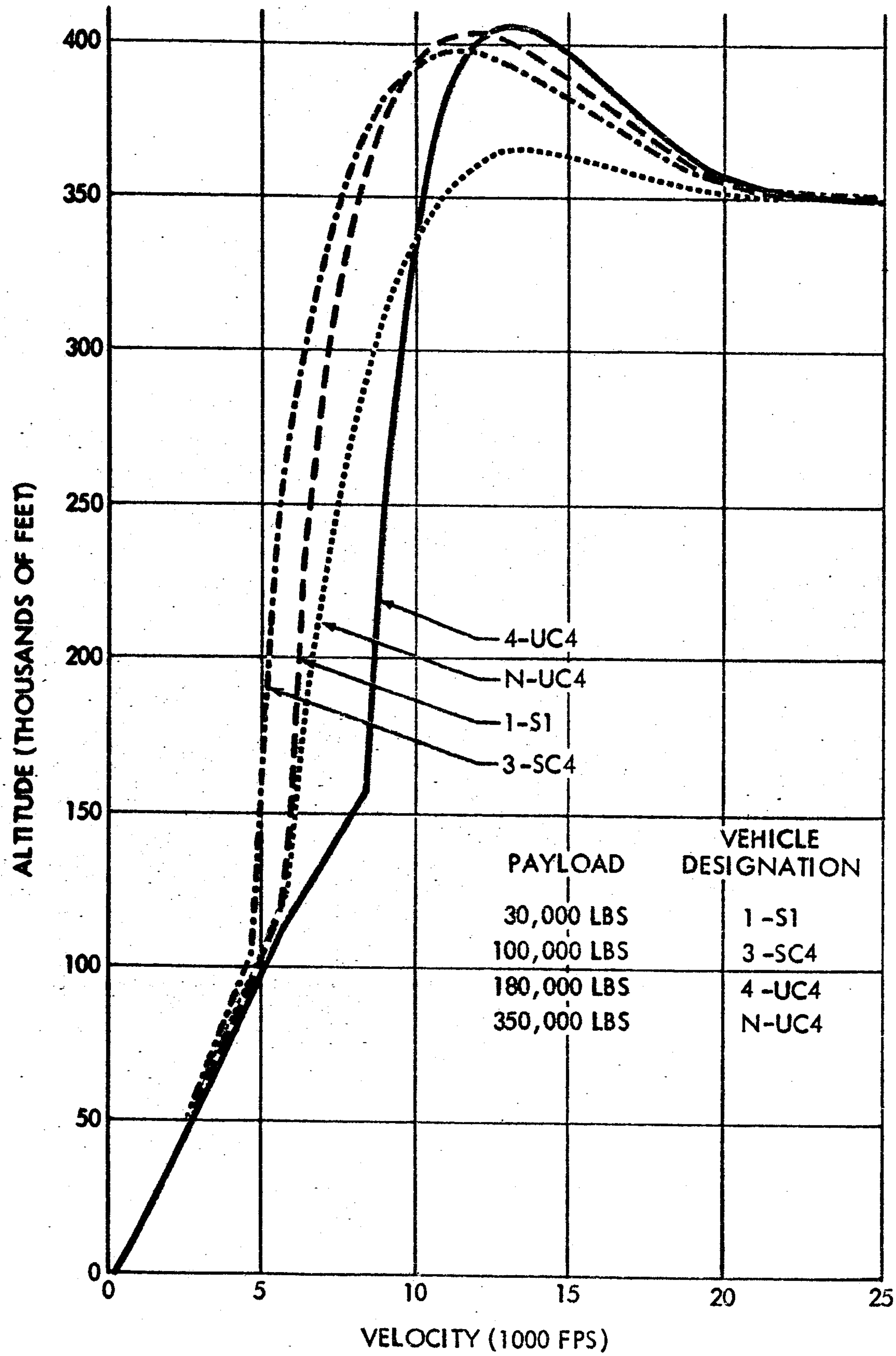


Fig. IV A1-6 TRAJECTORY CHARACTERISTICS

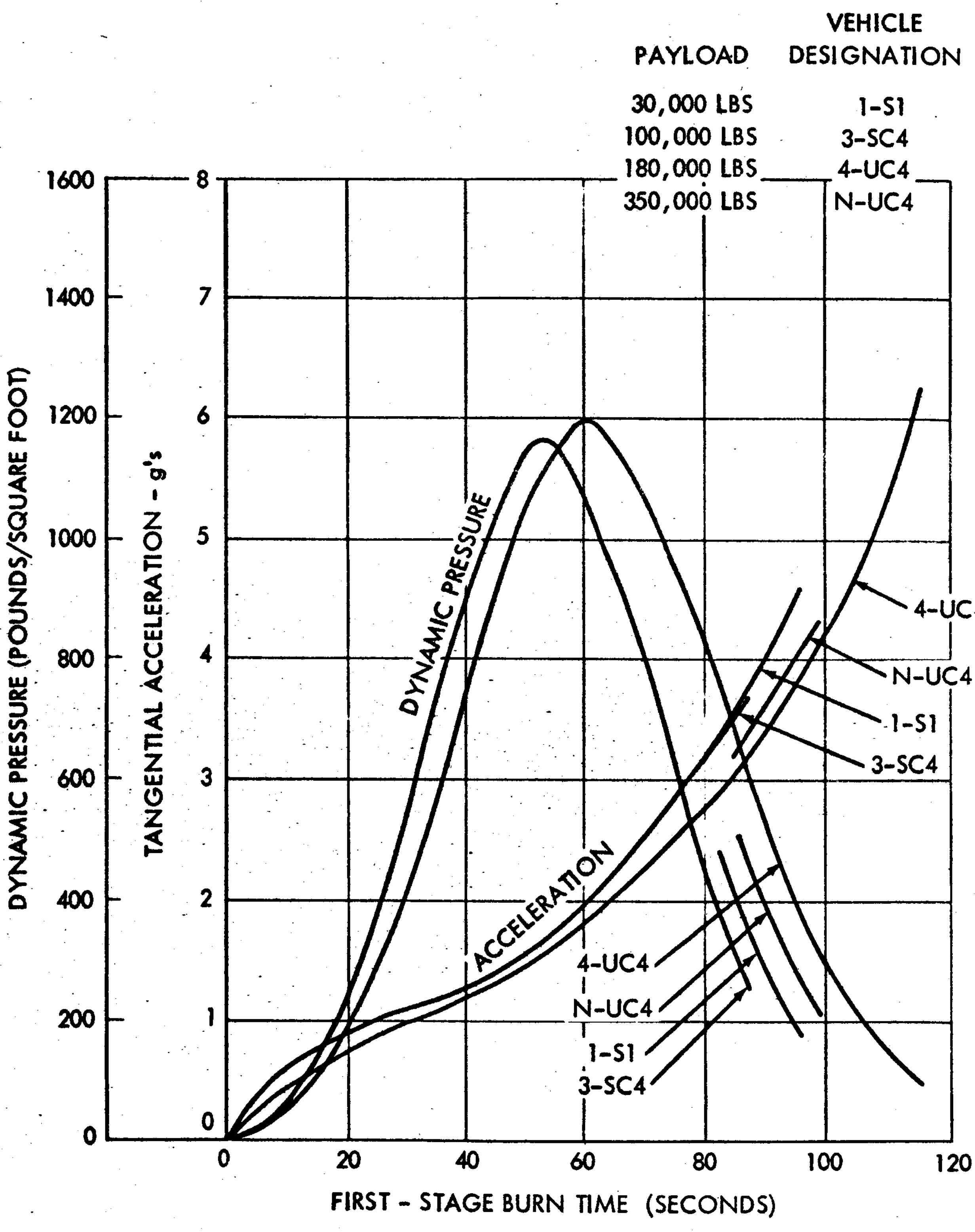


Fig. IV A1-7 TRAJECTORY CHARACTERISTICS

The payloads and launch weights of the final vehicles are shown in Figure IVA1-8 where a comparison is made with values determined in the Phase I parametric study. The final vehicles have higher launch weights than was indicated in the parametric study because of differences in λ's, thrust-to-weight ratios and first-stage burn times. The payload-to-launch weight ratios are compared in Figure IVA1-9.

TRADE STUDIES

Trade studies were made to determine the effects on performance of several parameters that were fixed by the ground rules. These include an expansion-ratio study, a chamber-pressure study, an engine-out study and an investigation of thrust-time histories other than neutral burning.

Expansion-Ratio Study

The base-line vehicles used an expansion ratio of 8. An investigation was undertaken to determine the effects of increasing the first-stage expansion ratio, ϵ, on performance. (See Figure IVA1-10.) The studies included the effects of ϵ on inert weight and specific impulse. Since the second-stage takeoff weight was constant for this study, the reduction in launch weight with increasing ϵ reflects a decrease in the first-stage weight. The maximum ϵ that results in the nozzle exit diameter within the motor diameter (160 in.) is indicated on the plots.

Chamber-Pressure Optimization

The chamber-pressure study was accomplished using the same basic vehicle that was used for the ϵ study (vehicle 3-UC4). The booster performance and optimum trajectory for each chamber pressure was determined using the IBM 7090 computer. Chamber pressures of 300 to 1100 psia were assumed and the effect of chamber pressure on first-stage inert weight and specific impulse (and consequently performance) was determined. The expansion ratio at each chamber pressure was the maximum allowable that kept the nozzle diameter

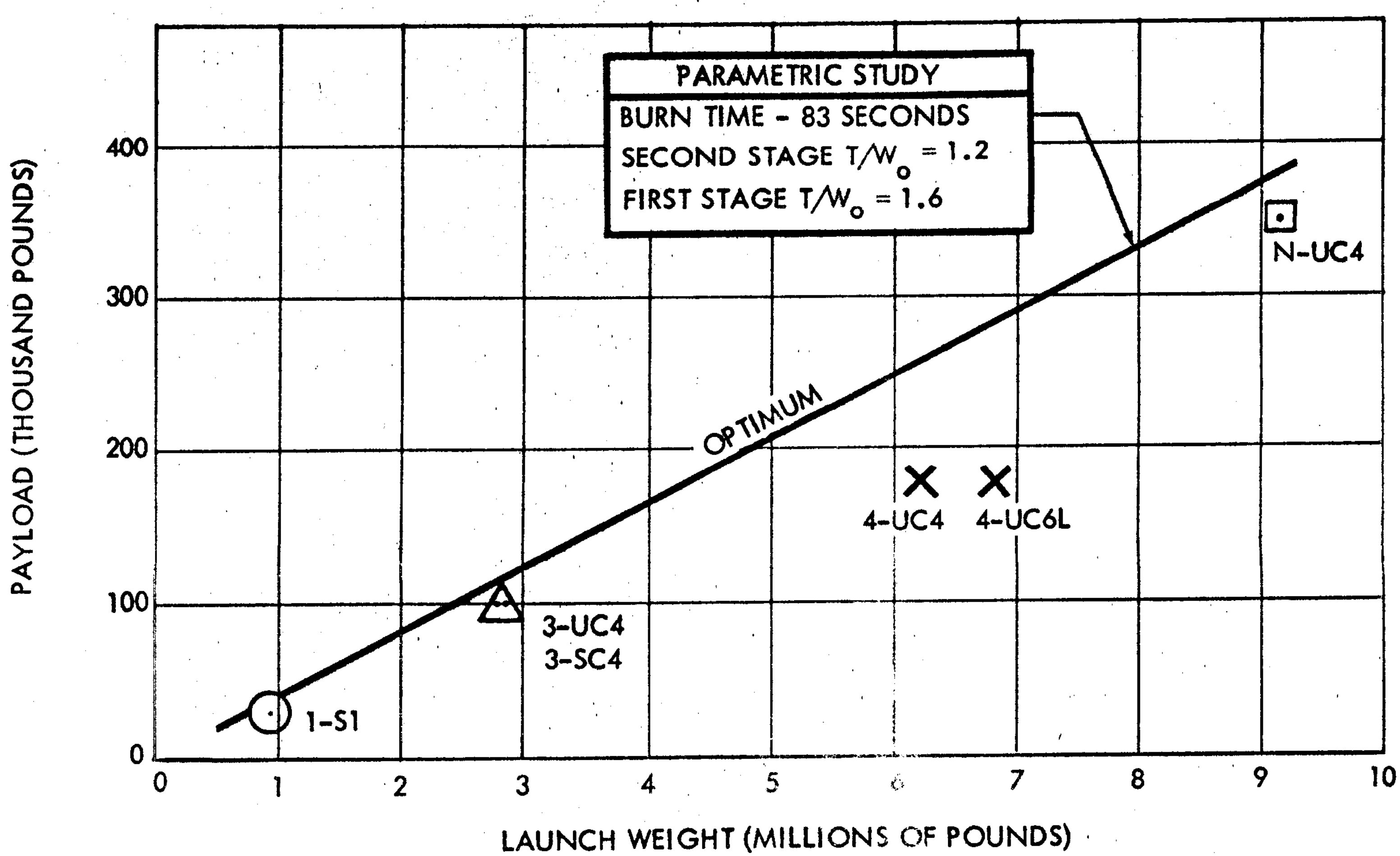


Fig. IV A1-8 PERFORMANCE COMPARISON OF FINAL SELECTED VEHICLES

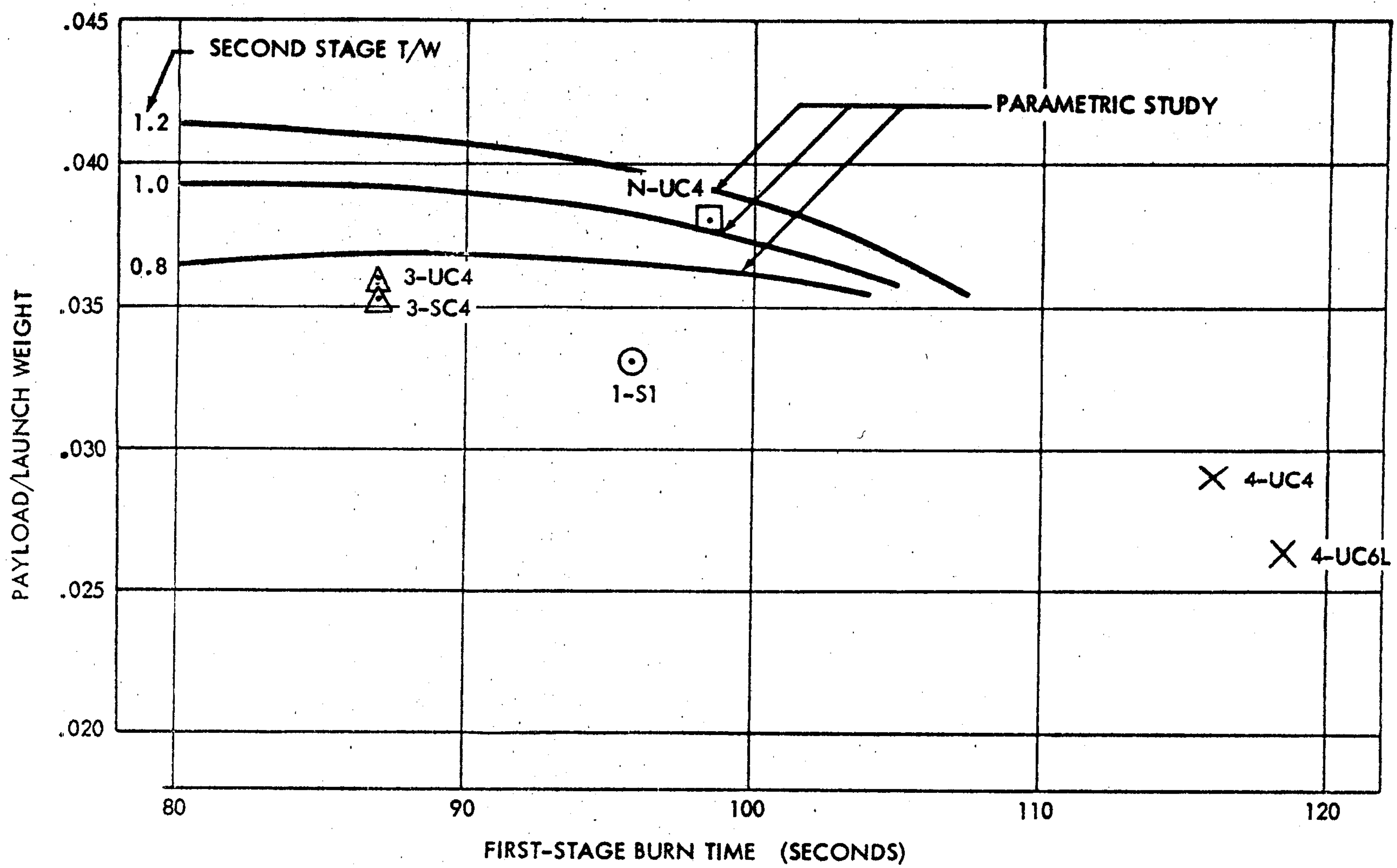


Fig. IV A1-9 PERFORMANCE COMPARISON OF FINAL SELECTED VEHICLES

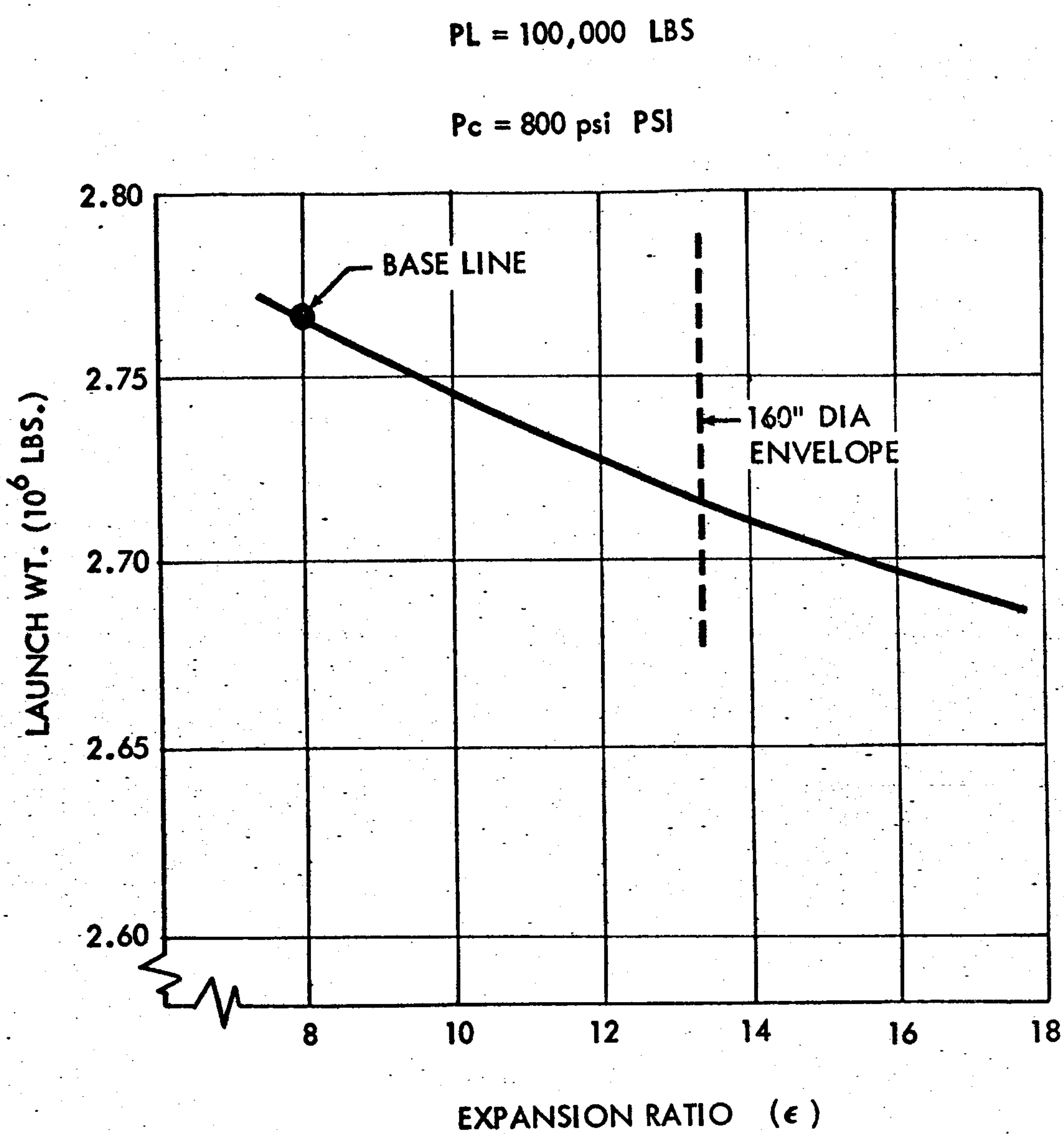


Fig. IV A1-10 EFFECT OF EXPANSION RATIO ON LAUNCH WEIGHT within the motor envelope. It was found in the study that an initial T/W ratio of 1.60 resulted in maximum "q's" above 1200 psf for chamber pressures of 500 psia and below. Therefore the study was done under two conditions. For one condition the initial T/W ratio was fixed at 1.60 and for the other condition the initial T/W ratio was that which resulted in maximum dynamic pressure of approximately 1200 psf. Both cases are shown in Figure IVA1-11 which shows launch weight as a function of chamber pressure. Launch-weight changes reflect changes in the first stage only as the second-stage weight was held constant throughout this study. A decrease in chamber pressure of the base line vehicle from 800 to 400 psia at an ϵ of 7 would reduce the launch weight approximately 5 percent.

This type of performance-optimization study should be treated with caution in trying to generalize solid booster design criteria. Optimum chamber pressure will vary with motor length-to-diameter ratio and will depend on whether the motor is segmented or unitized. Nozzle expansion ratio is often limited by space requirements in vehicle design and cannot be assigned arbitrarily.

Engine-Out Study

The baseline vehicles assumed all engines operative. A parametric study was made to determine the effects of having one engine inoperative in the second stage of the 100,000, 180,000 and 350,000 pound payload design-point vehicles. In each case the second-stage propellant weight was reduced until the resulting second-stage initial T/W ratios reached acceptable levels. The second-stage inert weight and the first-stage propellant weight and inert weight were the same as the baseline vehicles. The effect of the lower second-stage propellant weights (due to an engine out) on the payload capability of each vehicle was determined and is tabulated below.

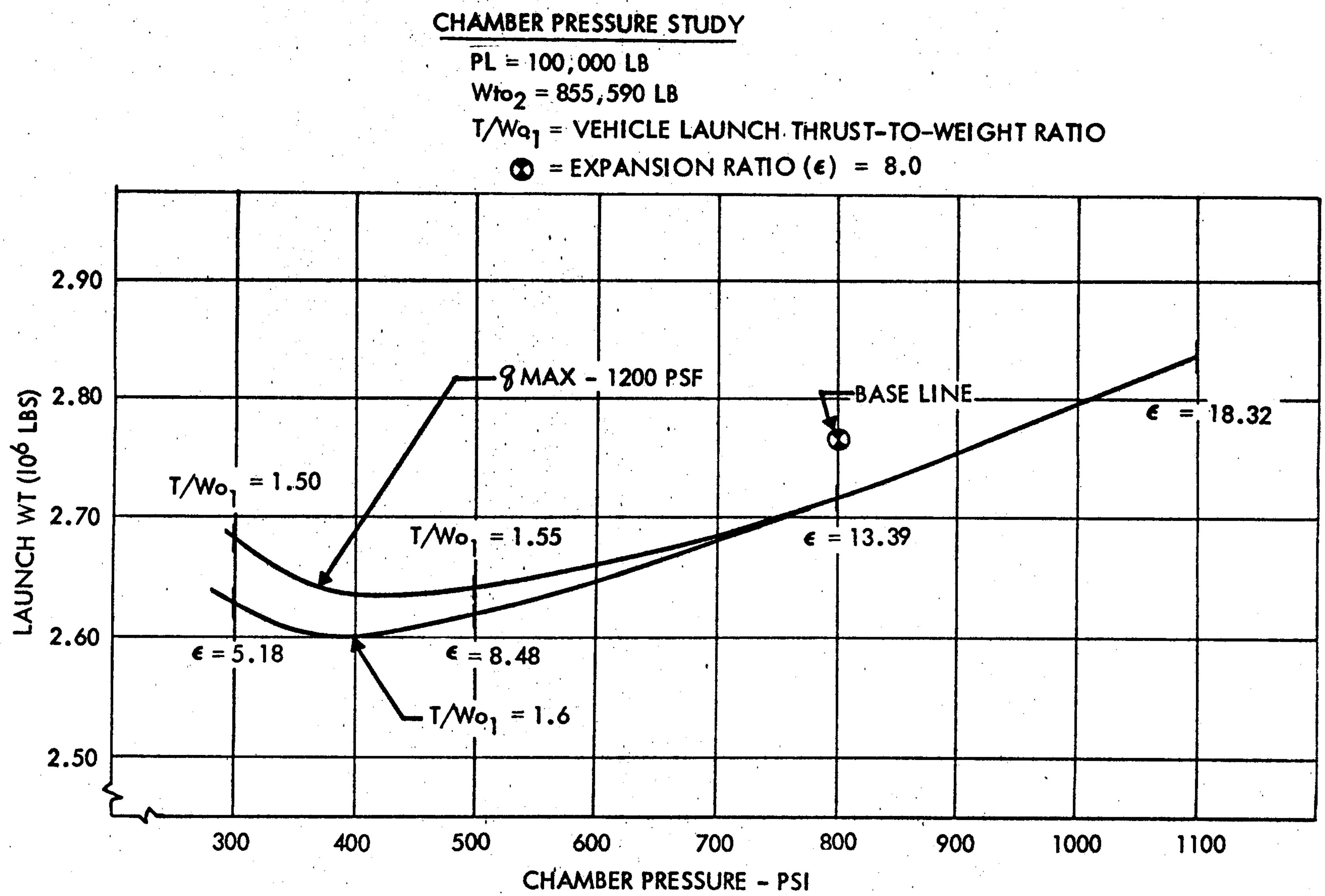


Fig. IV A1-11 EFFECT OF CHAMBER PRESSURE ON LAUNCH WEIGHT

	Baseline	Eng. Out	Baseline	Eng. Out	Baseline	Eng. Out
P.L.	100,000	73,800	180,000	138,500	350,000	298,000
W_{P_2}	700,000	634,000	700,000	507,750	1,950,000	1,765,000
T/W_2	.935	.945	.854	.854	1.22	.90
T_2	800,000	600,000	800,000	600,000	3,000,000	2,000,000

It is recognized that there are other and possibly more effective methods for providing engine-out capability for the vehicles studied, such as adding an extra engine in the second stage.

Thrust-Time History Study

The Phase II performance studies assumed neutral burning in the solid first stage. A study was made to determine what effects other thrust-time histories would have on performance. This study was made with the final 30,000-pound payload vehicle in which the first-stage propellant weight, inert weight and second-stage weights were the same as in the neutral burning case. The results of this study are shown in Figure IVA1-12. Progressive, regressive, and a combination of regressive-progressive thrust-time histories were studied using the IBM 7090 computer to determine trajectories and payloads. The data shows that a regressive thrust resulted in reducing the maximum dynamic pressure from 1160 to 1090 psf at the same payload while a regressive-progressive thrust could reduce the maximum to approximately 970 psf with an increase in payload of 1 percent. It is recognized that only a few of many thrust-time histories are included in this study and further work is required in this area. Other factors influencing a choice of thrust-time history would probably include first-stage boost velocity and trajectory flight-path angle history.

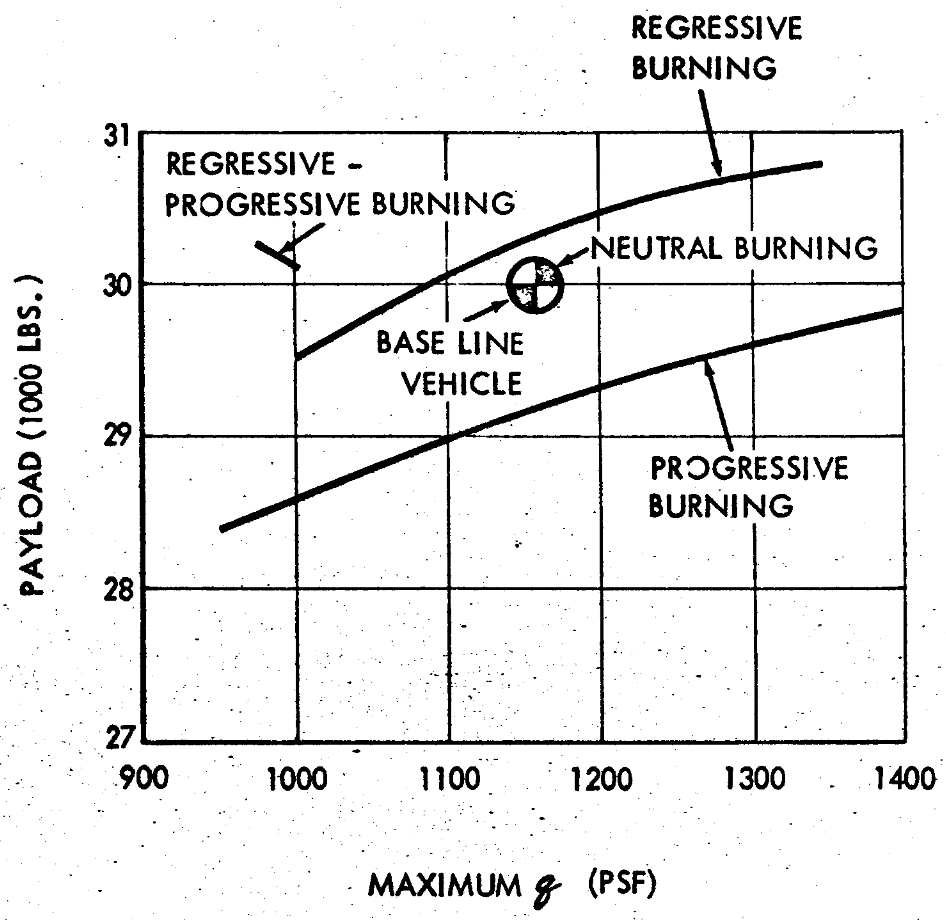


Fig. IV A1-12 THRUST - TIME HISTORY STUDY

2. PROPULSION

LARGE MOTOR FEASIBILITY

The technical feasibility of the large solid motors described in this study may be assessed upon the following considerations:

1) Their basis in demonstrated technology;
2) Understanding of the failure mechanism likely to be encountered in any scale-up of existing designs, and engineering approaches to overcome them;
3) Availability of materials, processes, and facilitates to accommodate any required scale-up of present motors.

Current Air Force large motor programs have provided for developing several aspects of large motor and grain design that have a significant bearing on the feasibility of motors described herein:

1) A large number of batches of propellant can be cast and cured successfully in a single motor or segment, over a cycle time of several days.
2) Motor segments can then be readily inspected, transported, and quickly assembled by the use of simple joints to form a complete motor case.
3) Insulation materials and techniques are available which can protect the motor case for the durations specified in this study.
4) Nozzle throat environment is no more severe than in smaller motors, a given erosion rate resulting in a much smaller percentage area growth.

Experience in these and other current programs also makes it possible to identify several directions of increasing risk in large solid motor development:

1) Larger grain diameter and longer unrelieved cylindrical length;
2) Increased web thickness, especially with star grain configurations;
3) Longer duration, through its influence on the nozzle requirements, especially with gimballed or hinged nozzles;
4) Use of higher strength materials, with higher notch sensitivity;
5) Higher propellant solids loading, through its influence on propellant processability.

Two self-limiting influences have become apparent in this study; solid-stage performance optimization within a maximum dynamic pressure of 1200 psf has tended to limit burning times to about 110 seconds and less, and cost considerations have tended to restrict the use of very high strength and highly notch-sensitive case materials and the requirement for very large motors. As a result, the motors discussed in this report are feasible, in the opinion of The Boeing Company. That is, they can be developed at acceptable risk, in the times and at the costs indicated.

MOTOR AND GRAIN DESIGN

Assumed Propellant Composition and Properties

Propellant data developed during Phase I of this study indicated that compositions proposed by the earlier NASA study contractors were comparable in ballistic performance and physical properties. On the basis of available information, the Thiokol "H" series polybutadiene acrylic acid propellant was selected as a reference system for the present study. Characteristics of this propellant are shown in Table IVA2-1.

Motor Design Concept

This study has afforded an opportunity to examine two basic large solid propellant motor design concepts—the one piece or monolithic motor, and the axially segmented motor. Motor-case material selection, pressure-vessel forming and assembly, and applicable stress factors are discussed in the Structures Section of this document. In evaluating the motor performance, near-constant thrust was assumed. From a nozzle-design viewpoint, this will require a constant-diameter throat section. This can be provided by a machined graphite throat insert, either one-piece, or segmented for the larger nozzle sizes. Segmentation of nozzles will require somewhat more development effort than the one-piece machining, but the latter may be fabricated presently only for somewhat smaller motors than those discussed in this study. Ablative material may also be used in the nozzle throat;

Table IVA2-1

SUMMARY OF PROPELLANT CHARACTERISTICS

Manufacturer	Thiokol Chemical Corporation
Propellant Designation	Typical "H" Series PBAA
Composition, percent	
Binder (fuel)	14
Oxidizer (ammonium perchlorate)	70
Aluminum	16
Physical Properties	
Density, lbs/cu. in.	0.0639
Tensile Strength, psi @ 77°F	110
Elongation, percent (strain at max. stress, @ 77°F)	58
Modulus of Elasticity, psi @ 77°F	260
Ballistic Properties	
Characteristic Exhaust Velocity, fps	5190
Specific Impulse, sec. (Pc = 1000 psia, Opt. Expansion @ S. L.)	248
Burning Rate Range, in/sec. @ Pc = 1000 (without significant compromise of I_{sp})	0.3 to 0.7
Specific Heat Ratio of Exhaust Gases, γ	1.18
Burning Rate Exponent, n (in expression $r = a\,Pc^n$)	0.285
Temperature Sensitivity of Pressure, π_K, percent per degree F.	0.10

about 0.75 inch of material may be removed, corresponding to an area growth of less than 10 percent during the firing. The use of pressure-molded plastic sections for either nozzle insulation or ablative liners will require extensive new tooling due to the sizes involved; but present materials and assembly techniques appear to be adequate.

Grain Configuration

Reference grain configurations for the segmented and unitized motors were chosen arbitrarily from designs submitted by Aerojet, Thiokol, and United Technology Corporation. Designs for the individual motors will be described in the following vehicle sections. General design criteria were:

1) Conservative web thickness and cross section loading to minimize grain stresses, mandrel complexity, and demands upon propellant burning rate.
2) Fully lined case for the best possible grain bonding and thermal protection for the case wall during tailoff.
3) Straight-through head- and aft-end webs for unitized grains to reduce grain and grain-to-bond stresses; head-end loading for segmented motors; booted and chromate putty-filled ends are assumed with the unitized grains for longitudinal stress relief and insulation. Ends of the segmented grains will be sleeved around the grain-liner joint to allow slight pulling away of the grain from the liner upon cure. This technique has been proven by United Technology in the P-1 motor.
4) Insulation thickness adequate for the anticipated requirement with a safety factor of 1.5 to 2.0 and projecting well beyond web burning penetration at the fore and aft ends of the unitized and segmented grains and at the inter-segment faces of the segmented grains.
5) Inhibition and slotting of the segmented grain as necessary to provide a reasonably constant thrust-time trace.
6) Taper of aft-portion of core configuration of higher L/D motors to maintain aft port to nozzle throat-area ratio equal to or greater than 2.0.

MOTOR OPERATING PARAMETERS

Optimization of Expansion Ratio and Chamber Pressure

Preliminary design of the motors shown in this report assumed the operating parameters listed in Table IVA2-2. Because of the decision at the outset of Phase II of this study to consider vehicles using only two stages to orbit (which resulted in longer stage-burning times and substantially different stress loadings than vehicles previously studied by the NASA contractors), it was decided to re-evaluate optimum nozzle expansion ratio and chamber pressure. The 3-UC4 configuration was chosen for the optimization study.

Structural, aerodynamic heating, and drag considerations effectively restricted the nozzle exit diameter to that of the motor. The first step of the optimization study was to determine the trend of the optimum expansion ratio at the nominal assumed chamber pressure of 800 psia. Nozzle and motor performance was determined as a function of expansion ratio. Delivered thrust coefficient and specific impulse are plotted against expansion ratio in Figure IVA2-1 and -2.

Using design data from previous NASA studies and assuming the 5-degree nozzle cant, the throat area and the nozzle exit area(required and available) were next calculated as a function of nozzle expansion ratio. The results are plotted in Figure IVA2-3.

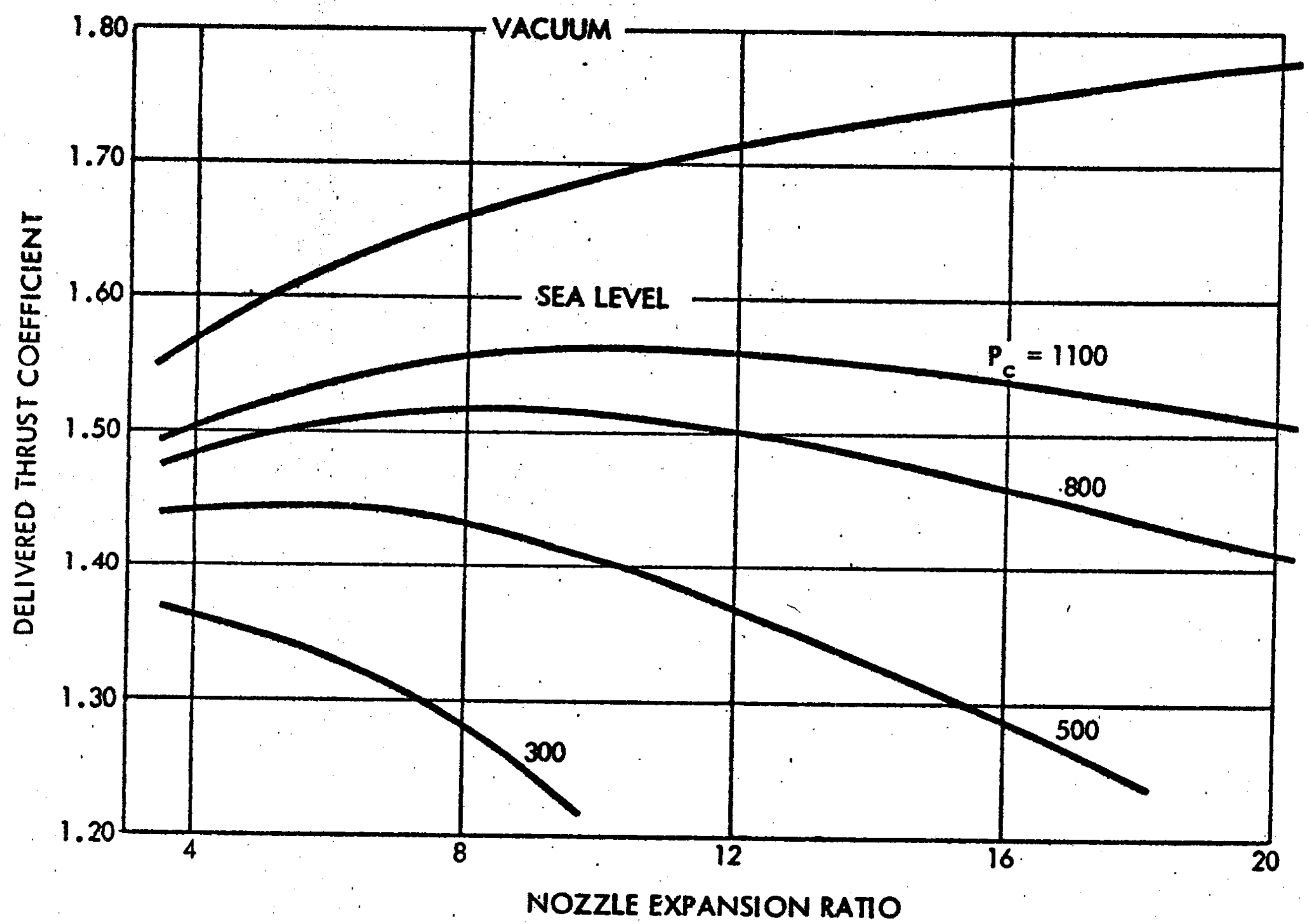
Performance evaluation of this vehicle showed clear advantage in using the maximum available expansion ratio. See the section on Performance for further details. It was therefore decided that the maximum available expansion ratio would be used in determining an optimum chamber pressure.

Available nozzle expansion ratio and corresponding motor performance were calculated as a function of chamber pressure. The results are plotted in Figure IVA2-4. This data, together with the associated motor weight data, provided the basis for a computer optimization of the chamber pressure.

Table IVA2-2

PRELIMINARY GENERAL OPERATING PARAMETERS NASA LARGE SOLID MOTORS

Operating Temperature Range, °F	80 ± 20
Nominal Chamber Pressure, Psia at 80°F	800
Maximum Expected Chamber Pressure, Psia at 120°F	926
Nozzle Type	Conical
Exit Half-Angle, Degrees	15
Cant (in clustered stages), Degrees	5
Expansion Ratio	8
Delivered Thrust Coefficient at S. L.	1.519
VAC.	1.664
Residual Misalignment, Degrees	0.25
Variation of Nominal Thrust at Given Temperature, 3σ Limit, Percent	± 4.5
Variation of Nominal Burning Rate at Given Temperature, 3σ Limit, Percent	± 3.5
Delivered Specific Impulse, Sec. at S. L.	240
VAC.	263
Minimum Grain Port to Nozzle Throat Area Ratio	2
Percent of Propellant Not Usefully Burned (sliver losses) Unitized Grains	1.0
Segmented Grains	0.25



$\gamma = 1.18$

$\eta_{NOZZLE} = 0.98$

CONICAL EXIT, 15° HALF-ANGLE

Fig. IV A2-1 THRUST COEFFICIENT NASA LARGE SOLID MOTORS

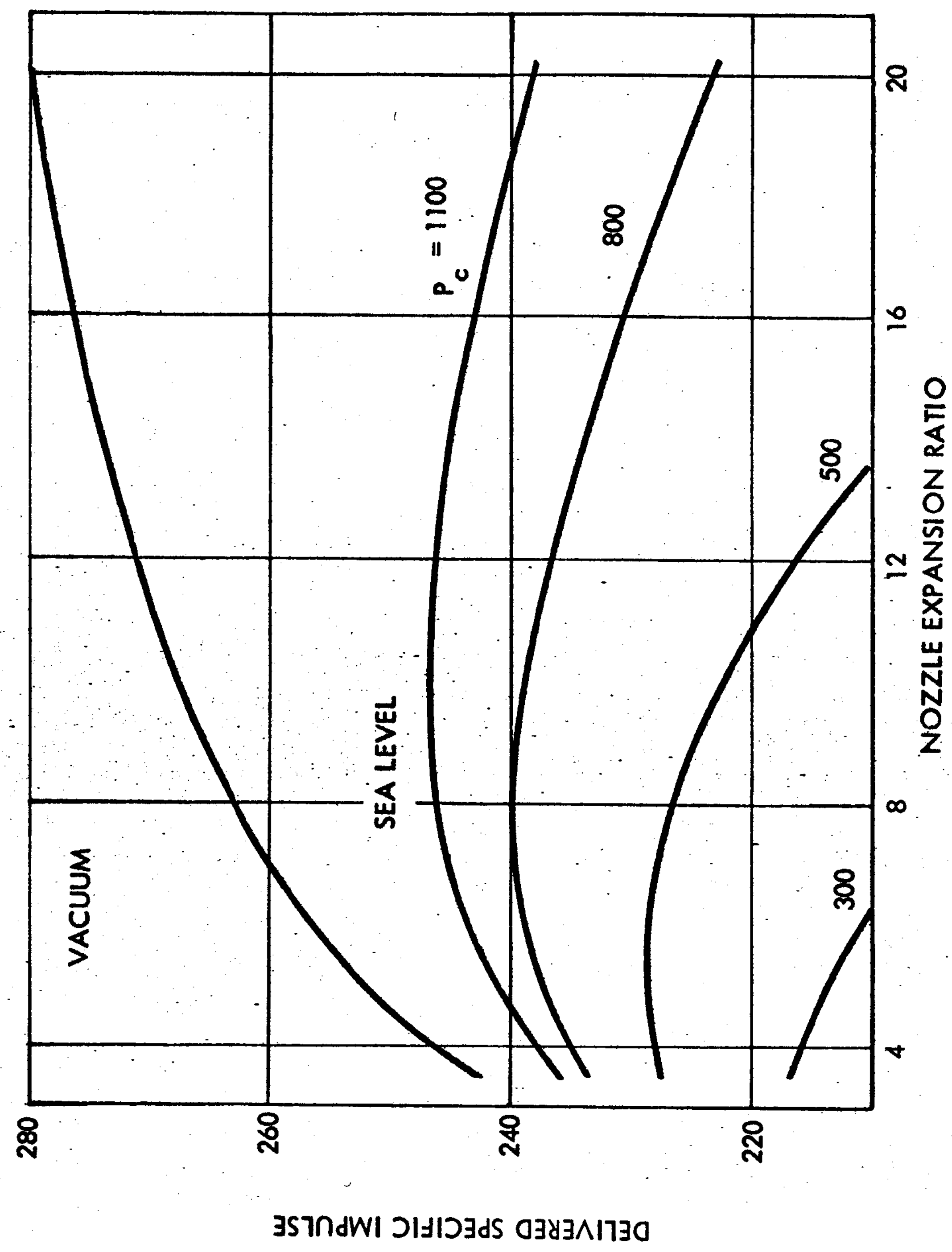


Fig. IV A2-2 SPECIFIC IMPULSE
(NASA LARGE SOLID MOTORS)

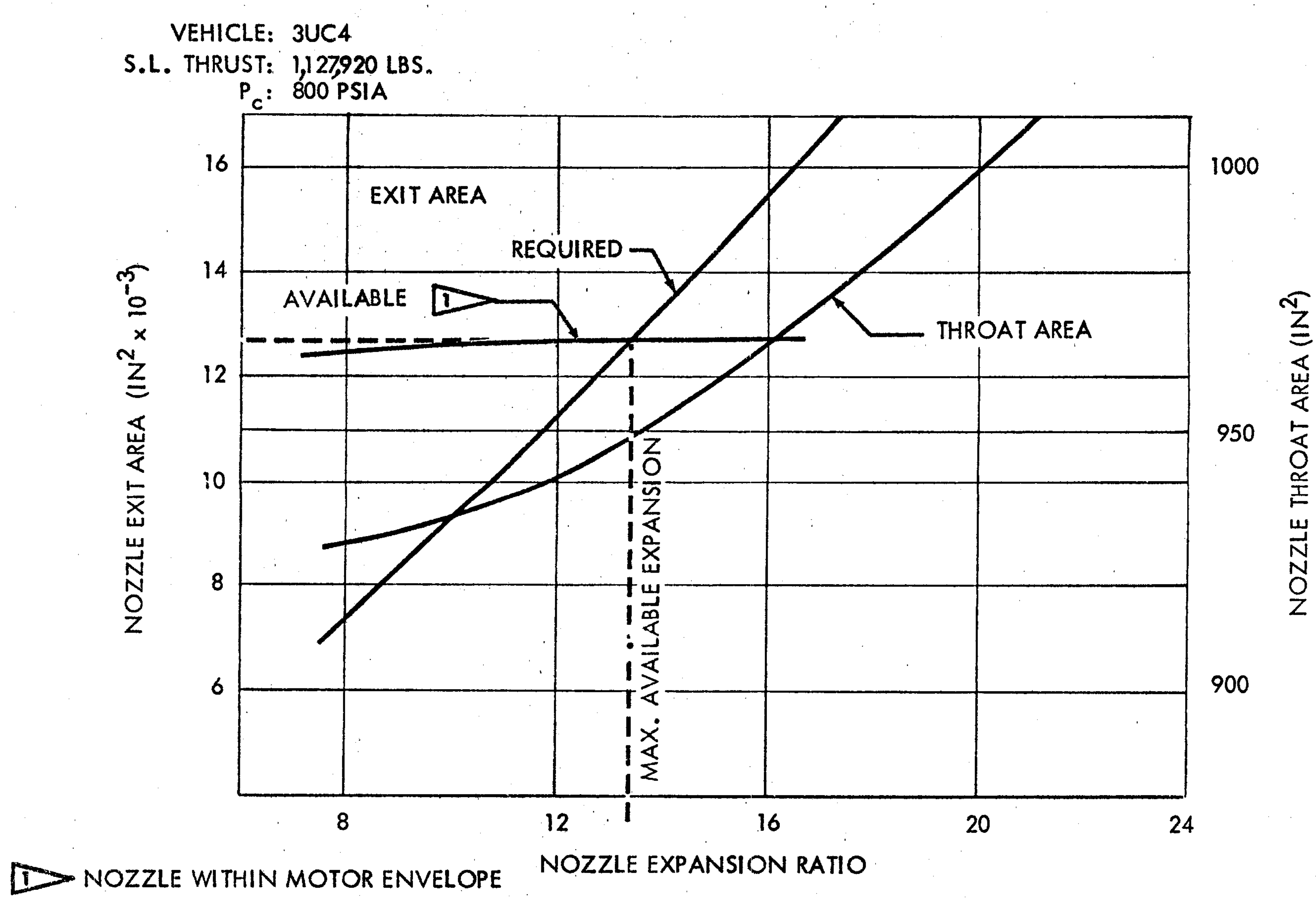


Fig. IV A2-3 THROAT AREA AND EXIT AREA AS A FUNCTION OF EXPANSION RATIO

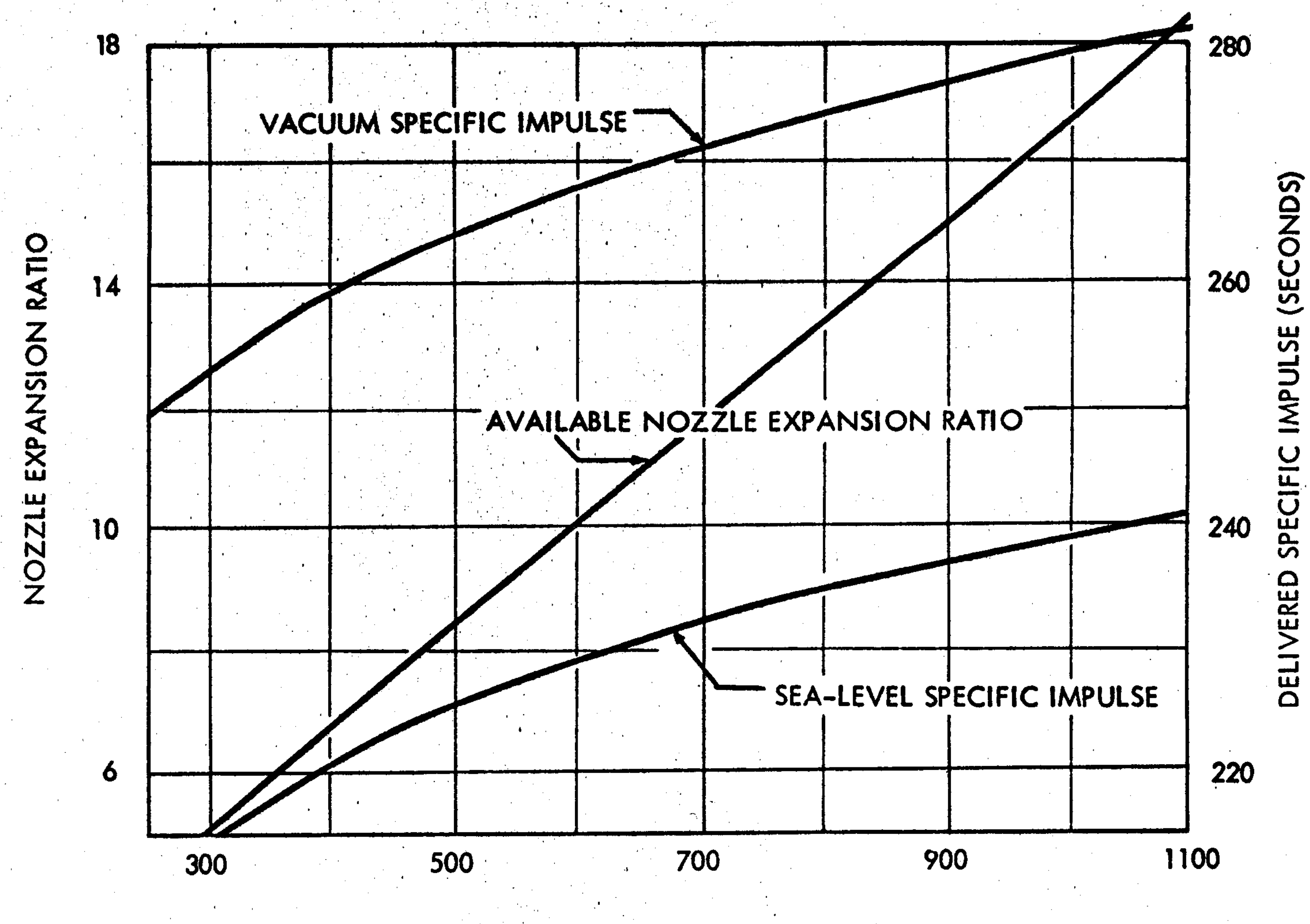


Fig. IV A2-4 EXPANSION RATIO AND MOTOR PERFORMANCE AS A FUNCTION OF CHAMBER PRESSURE

As the nozzle throat area increases to maintain constant thrust with lower chamber pressure, the grain-port-to-nozzle-throat-area ratio decreases (Figure IVA2-5). As this ratio falls, axial initial gas velocity and pressure drop increase with the associated tendency toward erosive burning. A port to throat ratio of 2.0 will prevent unpredictable erosivity of the grain. For the grain configuration assumed, this places a lower limit on operating chamber pressure of about 450 psia (Figure IVA2-5).

Since motor case weight is proportional to operating chamber pressure so long as it is pressure-designed, it remained to be determined if there was an advantage in reducing cross-section and motor-volumetric loading to enable operation at still lower chamber pressures holding the same port-to-throat ratio. Throat area increases sharply at chamber pressures below about 500 psia and available volumetric loading falls off steeply (Figure IVA2-6).

These data were also taken with associated motor case and nozzle weights and used in a computer evaluation of motor and vehicle performance. Performance optimization is discussed in the Performance Section.

It is of interest to note that the altitude at which the nozzles with maximum available expansion ratio expand the exhaust gases to ambient pressure, is much below the vehicle first-stage time mean operating altitude (Figure IVA2-7). With increasing chamber pressure, the nozzle throat area required for the specified thrust decreases and a larger expansion ratio is available within the motor diameter envelope. But optimum discharge altitude increases only slightly with increasing chamber pressure, remaining about half the booster time-mean altitude as estimated from the computed vehicle performance data. This is an indication that vehicle performance-optimized nozzles not subject to the structural and drag restraints imposed by these configurations would have larger expansion ratios. Separated flow in the maximum expansion ratio nozzles defined in Figure IVA2-7 is not likely to occur, since exit-to-ambient pressure ratios do not fall below 0.4.

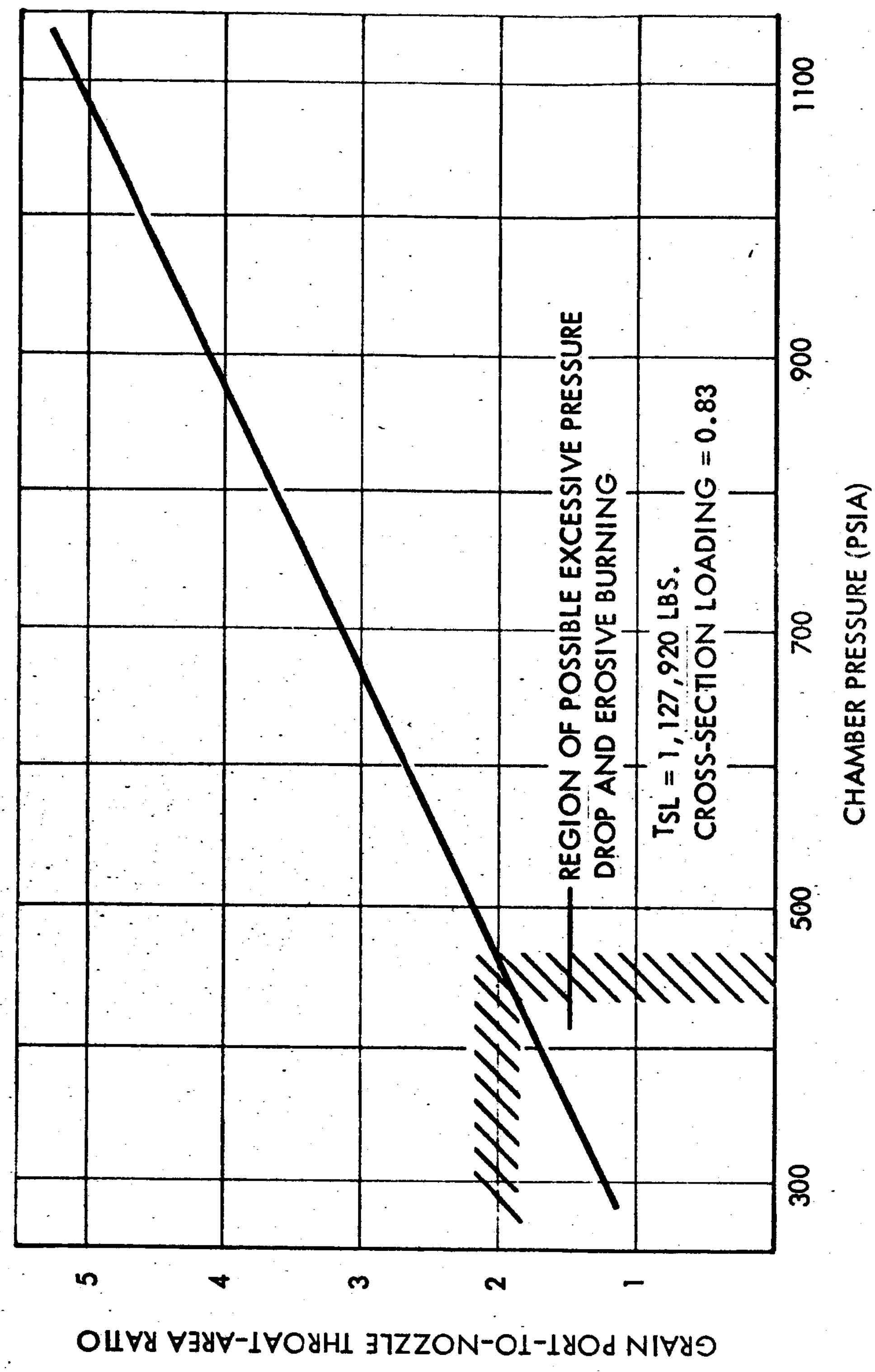


Fig. IV A2-5 PORT-TO-THROAT RATIO VS. CHAMBER PRESSURE

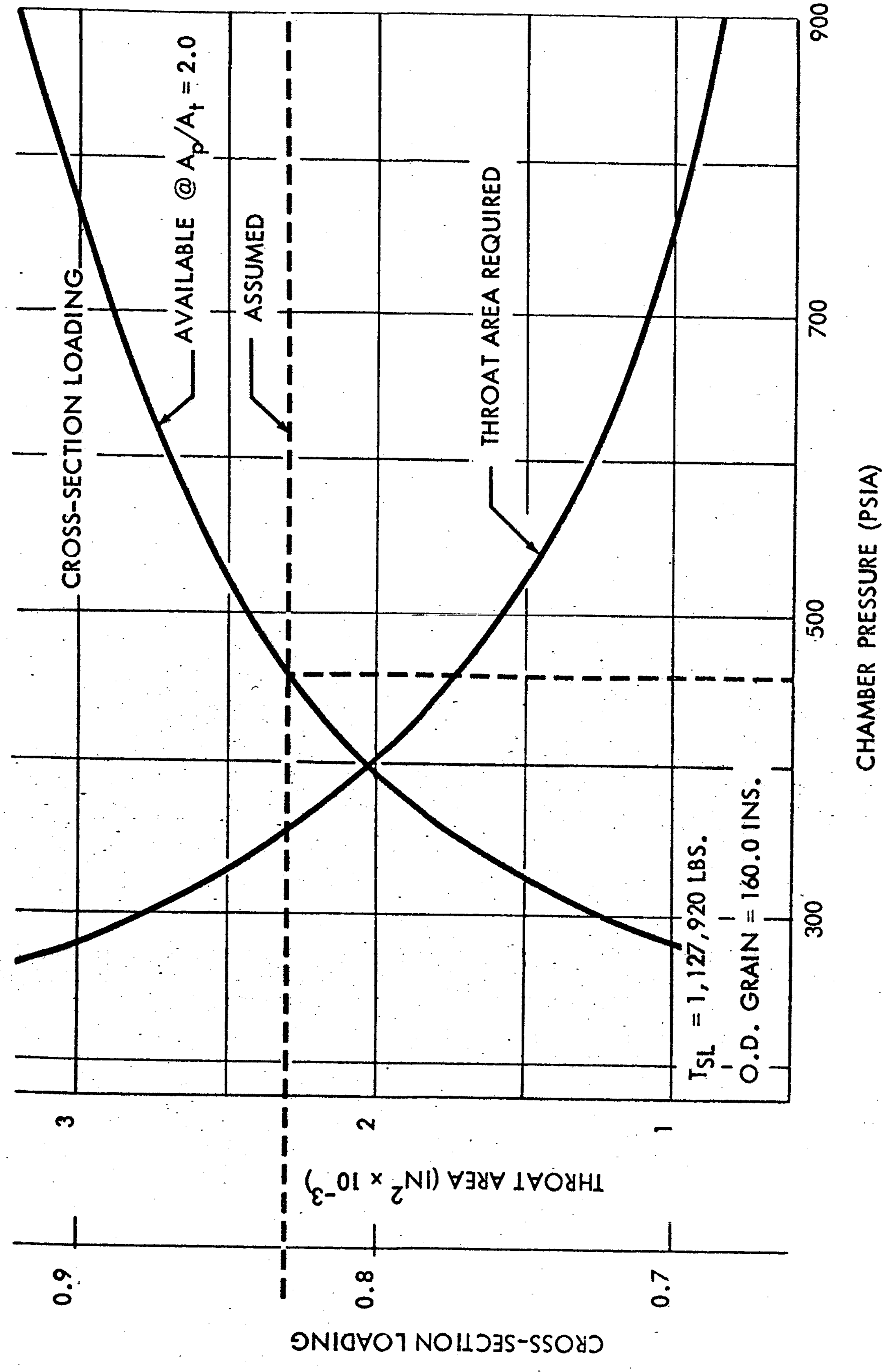


Fig. IV A2-6 CROSS-SECTION LOADING VS. CHAMBER PRESSURE

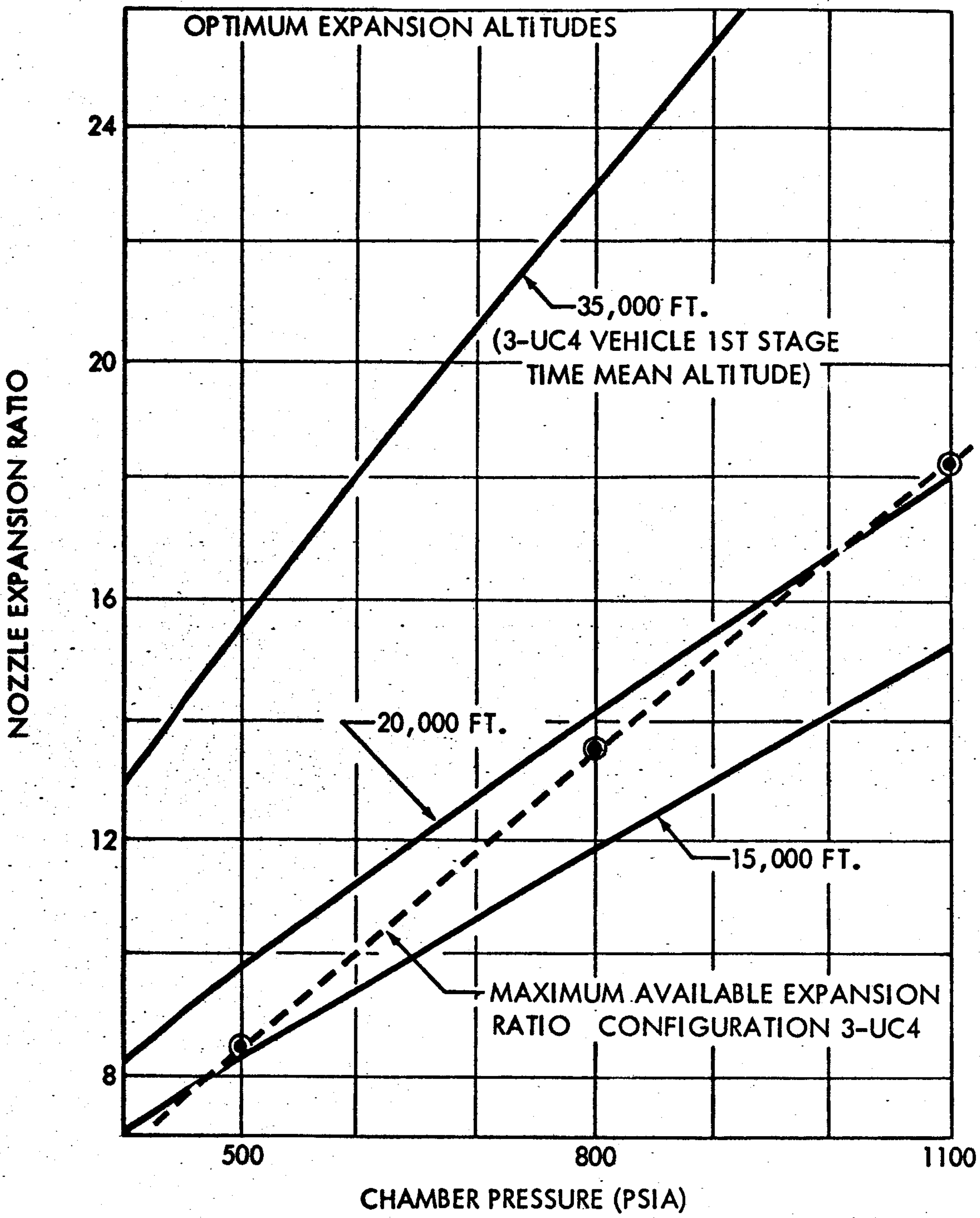


Fig. IV A2-7 OPTIMUM EXPANSION RATIO AS A FUNCTION OF ALTITUDE

Results of this optimization study indicate that the largest nozzle expansion ratio available within the motor envelope should be used, and that optimum chamber pressures for the solid propellant first-stage of these two-stage-to-orbit vehicles is in the region of 450 to 500 psia. It should be noted that these results were developed for specific motor configurations and may not generally apply.

Estimation of Maximum Expected Operating Pressure

To specify a maximum instantaneous operating pressure for motor case design purposes, the following factors must be considered.

1) The nominal thrust-time trace (as developed by the propellant grain burning area and nozzle throat area histories) and tolerances on their instantaneous values;
2) The influence of propellant ballistic properties (i.e., the burning rate coefficient, the burning rate exponent, and the pressure coefficient of temperature, (π_k) and the various tolerance effects on propellant composition upon these properties;
3) Nonprogramed variations in instantaneous grain burning area—cracks, voids, etc.

Numerical values for these factors were determined from Minuteman experience and the propellant properties given in Table IVA2-2. The maximum instantaneous pressure is calculated in the Structures Section of this document.

Further analysis of the variation of burning rate and chamber pressure and their influence upon the guidance and control of a clustered solid-stage vehicle was considered beyond the scope of this study.

NEW AREAS IN LARGE MOTOR DEVELOPMENT

Any normal engineering development project is characterized by necessary extensions of materials usage or techniques. A program of acceptable risk minimizes these extensions. While there is believed to exist an excellent technological basis for developing the large solid motors described in this report, some areas worthy of attention have emerged and are discussed in the following paragraphs.

Propellant and Motor Processing

In casting a large number of batches in a given segment or motor, it is important that steps be taken to assure adequate bonding to the liner. Premature curing of the liner might seriously weaken liner-grain bond strength in the area of the motor finally cast. Care must also be taken to avoid the requirements for excessive forces for core removal (with the attendant risk of serious motor damage). One manufacturer has proposed a sectioned mandrel to alleviate this problem with unitized motors.

Motor Ignitability

The length of the ignition transient might be affected by condensation of atmospheric moisture on the propellant surface. Handling and assembly of segmented motors appears to afford more opportunity for this to occur than with unitized motors. In view of the serious effects caused by dispersion of the ignition transients in a clustered stage, serious attention should be given all aspects of ignition and ignitability.

Motor Detonability

A motor shown to be detonable under any circumstance it might encounter in its life span will not be acceptable for manned flight. Particular care must be taken that the stage-destruct system will not induce sympathetic detonation of the propellant remaining after initiation of the escape sequence. For this reason also, it is proposed that the destruct system not be actuated until the manned capsule has achieved a significant separation. The problem of detonability is further discussed in the following paragraphs.

INFLUENCE OF PROPELLANT MASS UPON DETONABILITY

Detonability in solid propellants is a very important consideration in the design of a solid propellant rocket system. The basic questions are:

1) If a solid propellant grain is thermally ignited, will the deflagration transform to a detonation if the size is above some critical value?
2) If subjected to shock, will a propellant detonate?
3) Is a composite solid propellant as shock sensitive as a double-base or a plastisol propellant?

Much work has been done by many investigators (References 1 through 4) to explain the burning or deflagration reaction and its transformation to detonation, in both homogeneous and heterogeneous propellants.

Propellant Types

There are two types of propellants. They are the homogenous type and the heterogeneous type. Conventional explosives, double-base propellants, and plastisol propellants are homogeneous. PBAA, polyurethane, and all other composite propellants are heterogeneous.

Definition of Deflagration and Detonation

Deflagration is commonly referred to as burning. In the normal process of burning a solid propellant grain, the propellant is thermally ignited on an outside surface and burning progresses in a direction normal to this surface. Gas flow from the surface causes pressure to build up to the normal design pressure of the rocket chamber. Based on the fact that the rate of gas generation at the propellant burning surface must equal the mass flow rate through the nozzle, an equation relating propellant and rocket motor parameters may be written as

$$r \rho A_s = \frac{g P_c A_t}{C^*} = \dot{w}$$

where ρ = propellant density

A_s = burning surface area

A_t = exhaust nozzle throat area

C^* = propellant characteristics exhaust velocity

$\dot{w}$ = propellant consumption rate, lb/sec

Thus, chamber pressure and propellant consumption rate for any particular deflagrating propellant in a particular rocket motor can be increased only by an increase in burning surface.

Detonation is a special condition where the reaction velocity is so rapid that a wave (called the detonation wave) is propagated through unreacted explosive or propellant due to an advancing shock front behind which rapid exothermic reaction occurs in such a way that the heat release supports further propagation of the detonation wave. This process depends on the generation of hot spots by the advancing shock front which then ignite the propellant or explosive material.

The burning rate for both deflagration and detonation is proportional to the pressure and may be expressed as

$$r = r\,(p)$$

and as written above

$$\dot{w} = r\,\rho\,A_s$$

In the special case of detonation, A_s is the area in combustion; the only difference being that it is not an external surface as in the case of deflagration. According to Reference 2, this equation has been very fully confirmed for pressures up to about 10,000 atmospheres.

The basic difference between deflagration and detonation is that in deflagration the products of combustion move away from the reacting surface, whereas in detonation they move toward it, thereby building up pressure and maintaining a shock wave. Therefore deflagration is dependent on ambient pressure but detonation is completely independent of ambient pressure.

Reaction Mechanisms

The reaction process for composite propellants involves the following steps.

1) Surface decomposition of the oxidizer grains occurs to produce volatile intermediates. In the case of ammonium perchlorate, this is believed to be represented by the equation

$$NH_4 Cl O_4 \longrightarrow H Cl O_4 + NH_3$$

2) The oxidizer decomposition products (perchloric acid, $H Cl O_4$ and ammonia, NH_3) react and produce some heat.
3) The fuel binder is vaporized.
4) The fuel vapors and oxidizer decomposition products diffuse, mix, and react with high heat release to produce the final combustion products.

The reaction processes for homogeneous propellants involves

1) Decomposition of the surface layer into volatile intermediates. This reaction is not self-sustaining.
2) The intermediate products react with high heat release to produce the final combustion products.

The reaction processes for the two types of propellants differ in one very important aspect. Composite propellants depend on diffusion of oxidizer and fuel vaporization products to support deflagration, whereas homogeneous propellants do not. Reaction rate of composite propellants is limited or controlled by this diffusion process. Homogeneous propellants have the oxidizer and the fuel constituents either as integral parts of the molecules, or in solution. They are therefore already "mixed" and diffusion into the reaction zone is not a consideration.

Detonability of Homogenous Materials

Thermal ignition of homogeneous propellants or homogeneous explosives produces initially a burning or deflagration. However it is possible for the burning rate to increase and become as high as 2000 to 8000 fps so that a shock-wave front develops to establish a detonation. A minimum or so-called critical mass of propellant is necessary to allow this.

The critical mass varies with the material. For lead azide, the critical mass is too small to measure; for TNT the value according to Reference 2 is about a ton. The value for homogenous propellants would probably be greater than this. However, if TNT is subjected to shock from some shock initiator such as mercury fulminate or lead azide, it will detonate in any size. Thus, the critical mass is related only to thermal ignition where burning transforms to detonation.

Detonability of homogeneous materials when subjected to shock depends entirely on the sensitivity of the material and the strength of the shock. However, there is no reason to believe that homogeneous propellants now in use cannot be detonated by shock if the shock is of sufficient strength.

Difficulty of Detonation in Heterogeneous Propellants

The propellants considered for the NASA study are composite solids composed of ammonium perchlorate particles, aluminum powder, and a hydrocarbon binder. Neither the aluminum powder by itself nor the hydrocarbon binder by itself will explode or react; also in combination with one another they will not react. Thus these two ingredients are not considered to be explosive materials.

Ammonium perchlorate, however, decomposes when heated and produces some heat in the process in much the same way as a homogeneous double-base propellant.

When these materials are mixed in the proportions used in composite propellants now in use, the mixture is not an explosive material. Thus, when a normal composite propellant grain is thermally ignited, the burning rate builds up to an equilibrium value and remains constant no matter how large the grain. This burning rate for most composite propellants varies from 0.3 to 0.6 inches per second.

Effect of Cracks and Porosity

Cracks in a propellant grain would permit a penetration of hot combustion products which would increase the area burning. This would increase the chamber pressure which would then cause further penetration. Therefore pressure would build up to a value high enough to cause a pressure vessel burst.

Porosity would have a different effect. These pores, when subjected to a shock wave front, can act as adiabatic heat sinks and develop hot spots distributed throughout the propellant grain. This could cause a bulk deflagration which would constitute an explosion; or (depending on the degree of porosity, oxidizer content, and particle size) a detonation.

Oxygen dissolved in the binder is particularly objectionable in a composite propellant because the diffusion process would be of less importance in limiting the energy release rate of the binder.

Fortunately composite propellants are processed under vacuum to eliminate dissolved gases. Many propellants have densities which are greater than 99% of the theoretical density.

Improper handling of the propellant grain may also produce porosity. It is possible for oxidizer-binder separation to occur if the propellant is subjected to very low temperature.

Conclusions

The following conclusions are made from considerations of reaction mechanisms, methods of ignition and propellant type.

1) Homogenous propellants may be detonable when subjected to shock, depending on the sensitivity of the material and strength of the shock wave.
2) Homogenous propellants may transform from deflagration to detonation if the mass is great enough. However this would probably be extremely large—larger than the grains designed in this NASA Solids Booster Study.

3) Composite propellants of the composition now in common use, if free from porosity and cracks, are not detonation-sensitive and will not develop a deflagration to detonation transformation.

MOTOR SUBSYSTEMS

Thrust Vector Control

During the period covered by this report, secondary-liquid injection thrust-vector-control systems were analyzed to obtain preliminary design data for the large solid boosters being considered. The maximum total side force required for thrust vector control was calculated at maximum dynamic pressure and the total control impulse required was estimated to be 1-1/2 percent of the vehicle total impulse. To satisfy these requirements, Freon 114B2 with a hydrazine monopropellant gas pressurization feed system was selected for analysis. In view of the large Freon weight requirements for the Nova vehicle thrust-vector control system, a system using nitrogen tetroxide as an injectant was considered, and the use of this higher performance, though less dense, injectant appears to be desirable from a weight standpoint. The data obtained for each vehicle are presented subsequently. The injectant weights shown include a 10 percent allowance for servovalve leakage and for continual bleed through all injectors to eliminate plugging of the injector ports and to cool the injectors.

A Freon injection thrust vector control system layout for the 4-UC4 vehicle is shown in Figure IVA2-8.

An outline of the assumptions and calculations used in the liquid-injection thrust-vector-control system analysis follows:

A. TVC Requirements

1. Total Impulse, Side: Integral of side force versus time duty cycle

$(I_T)_{side}$ assumed to equal 1.5% $(I_T)_{axial}$

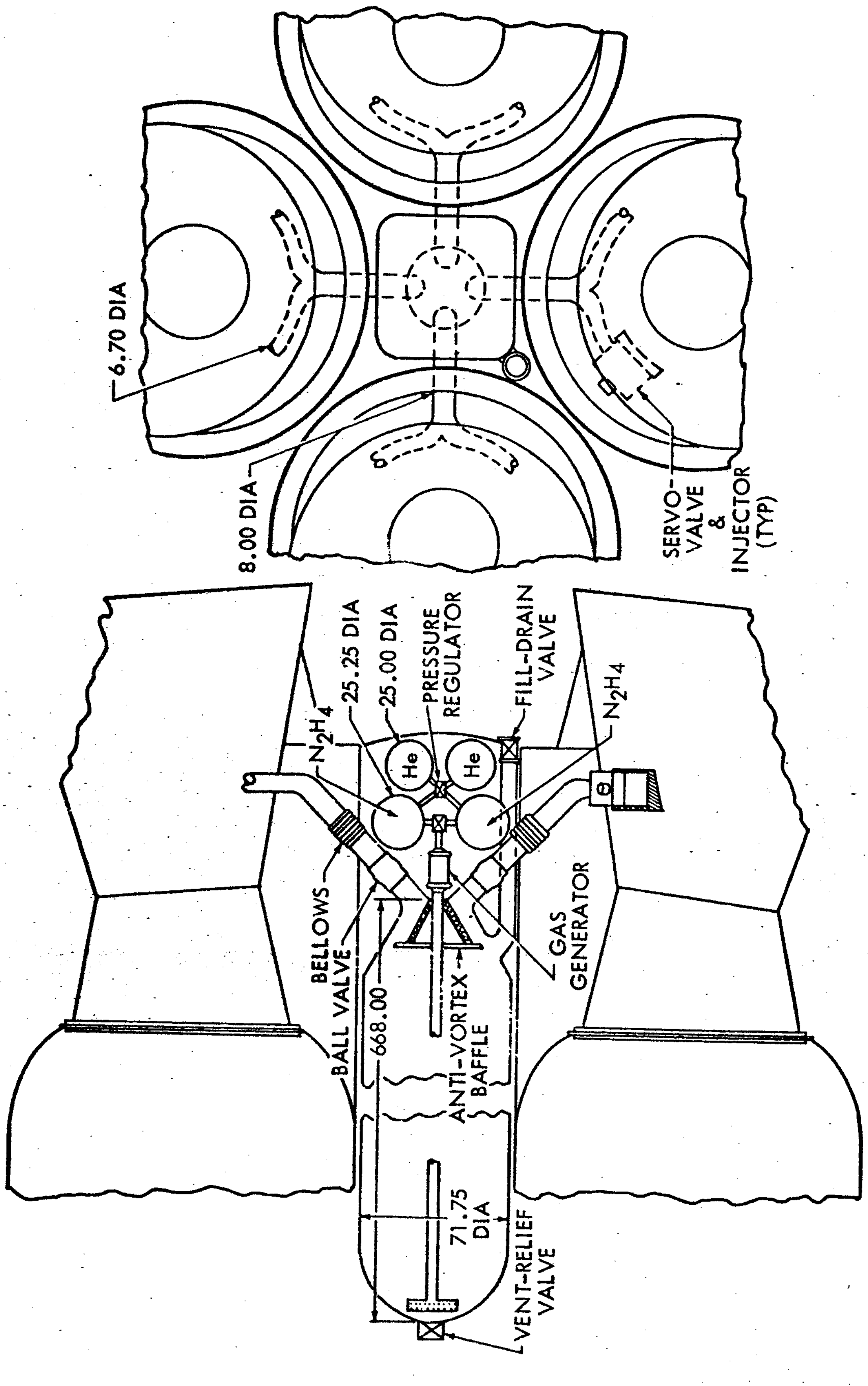


Fig. IV A2-8 TYPICAL FREON INJECTION TVC SYSTEM

2. Maximum Side Force

$(F_s)_{max.}$ calculated at $q_{max.}$

B. Injectant TVC Performance: (Figure IVA2-9)

1. Freon $(I_{sp})_{side} = 40\% \, (I_{sp})_{axial}$ up to $\delta = 2.8°$

2. N_2O_4 $(I_{sp})_{side} = 55\% \, (I_{sp})_{axial}$ up to $\delta = 4°$

$$(I_{sp})_{side} = \frac{\text{Side Force}}{\text{Injectant Flow Rate}}$$

C. Injectant Pressures

P_{inj} = 2 x Motor Chamber Pressure

(Based on Survey of Current Liquid Injection TVC System Designs)

D. Injectant Requirements

1. Weight

$$W_{inj} = \frac{(I_T)_{side}}{(I_{sp})_{side}} + \text{Allowances}$$

Allowances are included for servovalve leakage and continual leakage through all injectors to eliminate plugging of the injector ports and to cool the injectors.

10% Allowance Used

2. Volume

$$V_{inj} = \frac{W_{inj}}{\rho_{inj}}$$

ρ Freon-114B2 = 129 LBM/FT^3 at 80°F

ρ N_2O_4 = 89 LBM/FT^3 at 80°F

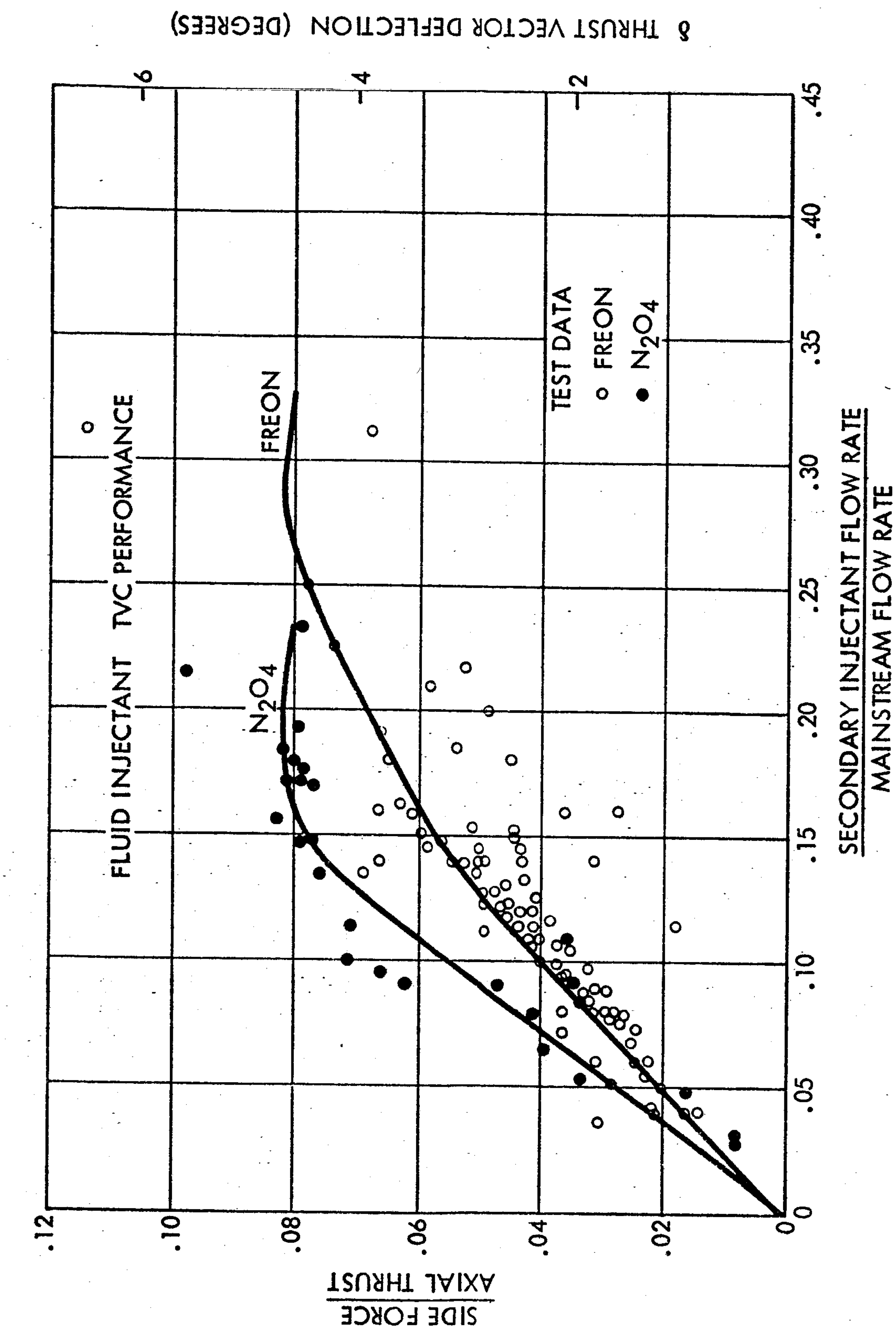


Fig. IV A2-9 THRUST VECTOR CONTROL BY SECONDARY INJECTANT FLOW RATE

E. Pressurization Systems—Injectant Feed

1. Helium Blowdown (Figure IVA2-10). From first low analysis of pressurizing gas treated as a closed system:

$$W_{He} = \frac{P_{inj} V_{inj}}{R_{He} (T_{He})_{min}} \quad \frac{\gamma_{He}}{1 - \dfrac{P_{inj} + (\Delta P)_{min}}{(P_{He})_{min}}}$$

$$(P_{He})_{min} = P_{He} \frac{(T_{He})_{min}}{T_{He}}$$

$P_{inj} = 1600$ psia $\qquad R_{He} = 386.3 \dfrac{FT\ LBF}{LBM\ °R}$

$(\Delta P)_{min} = 100$ psia $\qquad \gamma_{He} = 1.66$

$P_{He} = 5000$ psia

$T_{He} \pm \Delta T = 540 \pm 20°R$

$$W_{He} = 2.94\ V_{inj} \quad \text{LBM} \ (V_{inj} \text{ in } Ft^3)$$

$$V_{He} = .29\ W_{He} \quad Ft^3$$

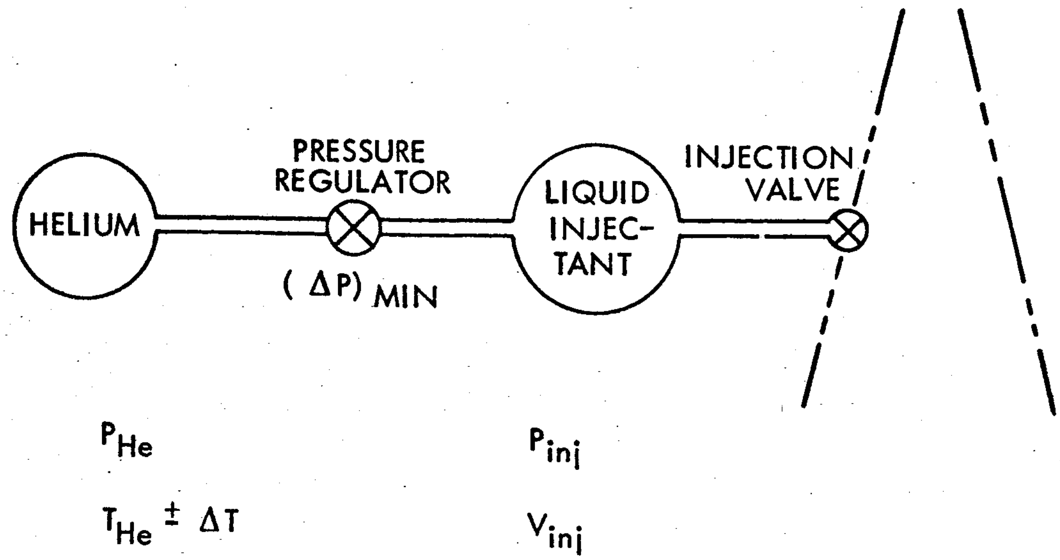
2. Hydrazine Monopropellant (See Figure IVA2-11). Hydrazine requirements for Freon pressurization and reaction chamber size adequate for the complete thermal decomposition of hydrazine in the absence of a catalyst, based on test data, are given in Figure IVA2-12.

a. Hydrazine Requirements

$$W_{N_2H_4} = 7.016\ (10^{-3})\ W_{Freon}$$

$$V_{N_2H_4} = \frac{W_{N_2H_4}}{\rho\, N_2H_4}$$

$$\rho\, N_2H_4 = 62.4\ LBM/Ft^3$$



IVA2-10

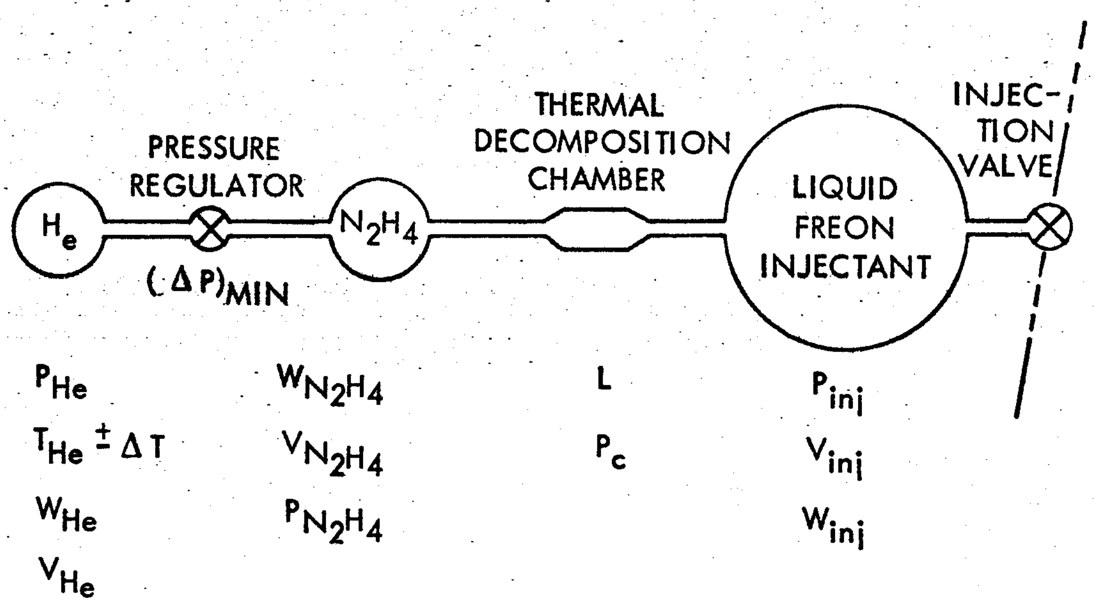


Fig. IV A2-11 HELIUM BLOWDOWN PRESSURIZATION SYSTEM

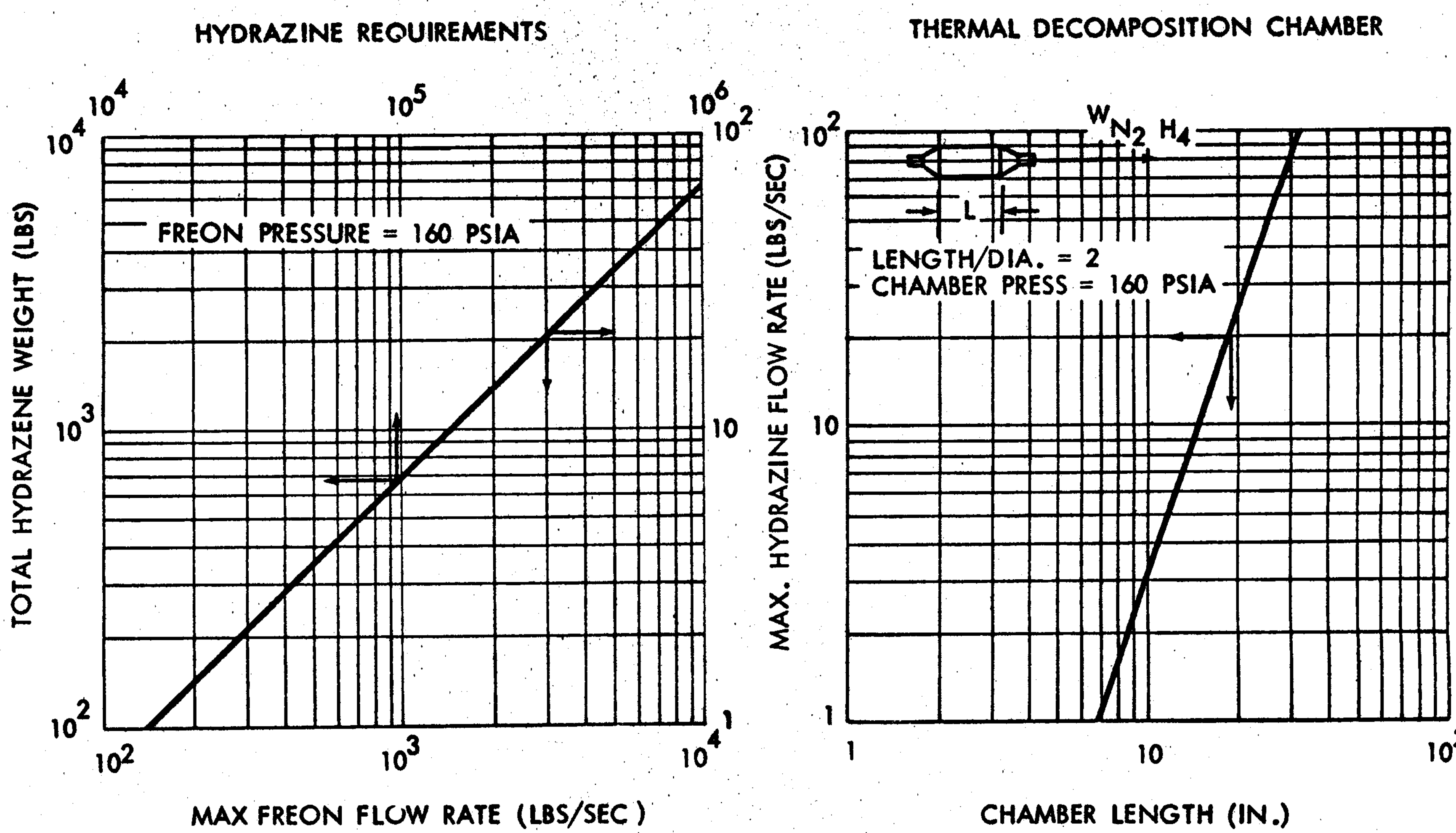


Fig. IV A2-12 HYDRAZINE MONOPROPELLANT PRESSURIZATION SYSTEM
FREON 114B2 INJECTION THRUST VECTOR CONTROL

b. Helium Requirements

(See Section E_1)

Ignition

Reliable and reproducible ignition of all motors in the solid-propellant stage is of critical importance. The complete ignition failure of one motor in a cluster of four would not prevent any of the vehicles of this study from lifting off and remaining controllable until the safety of the launch site could be assured. Crew escape could be undertaken at any time late in the countdown or early in the flight. However, a high dispersion of the ignition transients and the associated times and rates of motor case growth, places a severe requirement upon the load-carrying interstage structure.

An effort should be made in the detailed design of vehicles of this type to ensure that adequate ignition energy is delivered instantaneously to all motors of the cluster. Two general approaches in ignition system design have been suggested. In the first, a conventional Alclo-base pyrogen unit would be mounted through a boss at the forward head of each motor. The ignition sequence would be triggered through redundant electrical circuitry and initiators. In the second approach, a launcher-retained system, a central pyrogen would be manifolded either directly to the individual motors or to secondary pyrogen units projecting into each motor. A very high degree of "one-go-all-go" ignition reliability and simultaneity could be ensured by this system.

Current conventional ignition systems have been selected on the basis of reliability, as reference systems for the initial versions of all vehicles described in this study. It is suggested that the scope of present motor-manufacturer ignition studies might be expanded to include scale-up and test of launcher-retained systems. Data thus derived might well provide the basis for ultimate system selection.

Provision for Crew Escape

A fundamental question in the use of solid-propellant motors in large space boosters is that of crew and range safety. Both are dependent on the destruction of the first stage after detection of an impending catastrophic failure. However, because such destruction requires provisions for prior separation of the crew from the booster, it must be determined if a crew capsule accelerating within human tolerance can separate from the booster vehicle. Figure IVA2-13 is a plot of the initial net acceleration of an Apollo-type escape capsule and the 1-S1 boost vehicle as functions of the time during first-stage boost at which escape is initiated. The escape capsule is capable of the least net acceleration at high dynamic pressure, where it feels the highest drag. The booster will accelerate slightly faster when relieved of the escape capsule.

A measure of the thrust termination requirement is the minimum net acceleration between the escape capsule and the booster. It is assumed that the 1-S1 booster is at full thrust and the Apollo escape capsule W/C_DA is 90. Then the minimum net initial acceleration of the escape capsule away from the booster is about 3-1/2 g's, or about 110 feet in the first second. It can be concluded on the basis of these assumptions that thrust termination is not necessary for the first stage. However, this subject should be re-examined as Apollo escape capsule and booster detailed design data become available.

Destruct

Range safety considerations require that it be possible to render the solid-propellant stage nonpropulsive at any time during its operation. Experience with systems meeting conceptually similar requirements in current programs indicates that this can be accomplished rapidly (within a few milliseconds) by a linear shaped-charge jet perforator. To induce pressure failure, the solid propellant motor cases could be split axially and symmetrically, with respect to the stage, by a shaped charge designed to penetrate through perhaps 0.6 ± 0.2

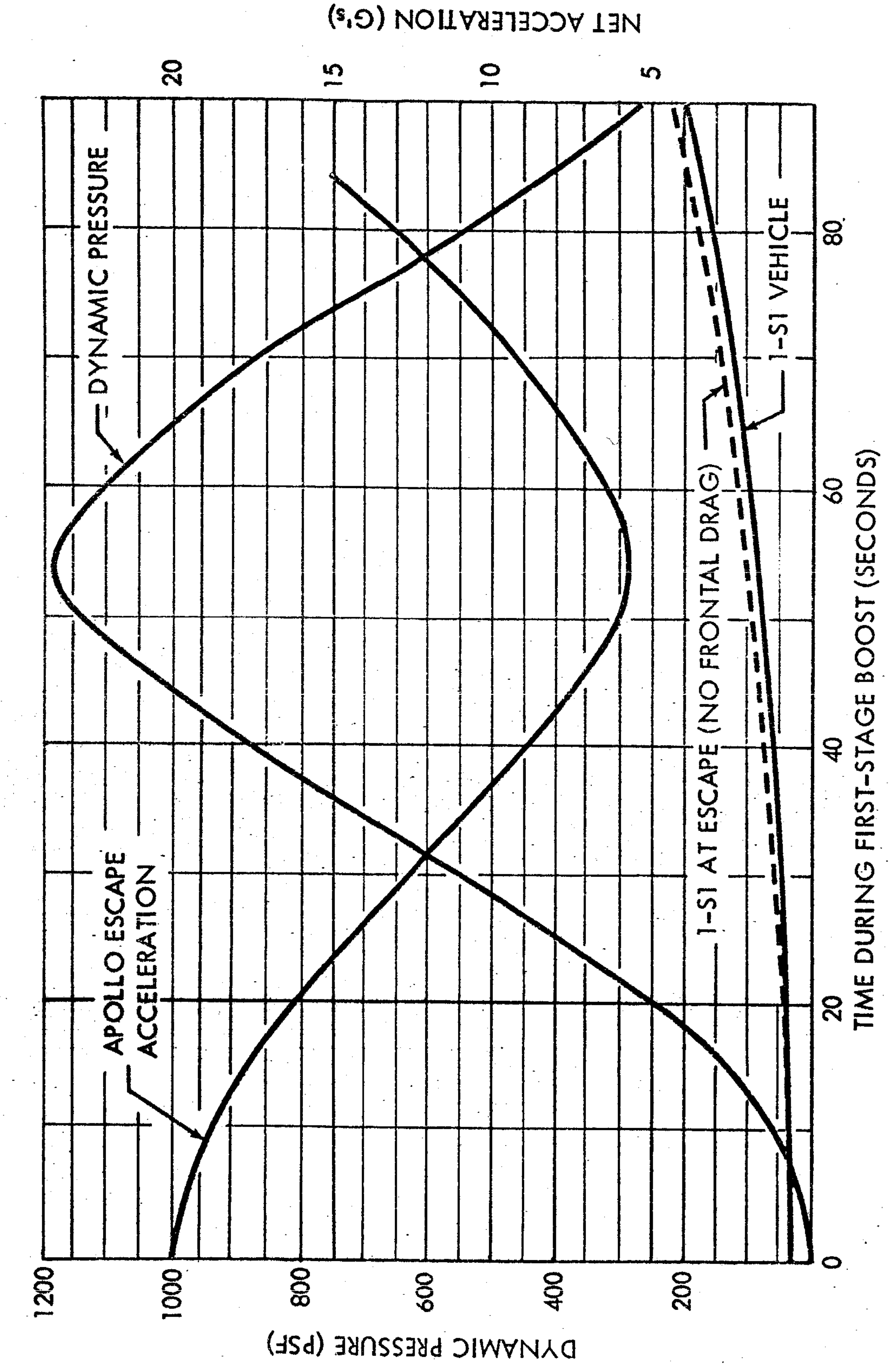


Fig. IV A2-13 ABOUT ESCAPE CAPABILITY OF PAYLOAD of the wall thickness. This system is referred to as the "partial penetration jet perforator" or simply "jet perforator" in the vehicle descriptions of the next sections.

ROCKET EXHAUST ATTENUATION OF VEHICLE COMMUNICATION SYSTEMS

Introduction

Communication with the six vehicles will be impaired by the ionosphere and by the exhaust plumes of the rockets. In Reference 5 relations have been shown of transmission coefficient in the ionosphere versus frequency for various polarizations, magnetic field directions, and altitudes. According to these curves the worst transmission conditions result in less than a 3-decibel loss of power at frequencies above 50 mc. The rocket exhaust plume presents a much more serious problem than the ionosphere. Telemetry information from various rockets (Reference 2) shows that the effects of the plume are noticeable at various times during the boost phase of flight. Ordinary flame attenuation is due to ionized exhaust products and is a function of the aspect angle—the angle between rocket roll axis and transmitter-to-receiver line of sight. This effect is present whenever the line-of-sight passes through the exhaust plume.

Effects at Staging

Reference 2 reports that several plume effects occur at staging—ordinary flame attenuation, plasma-enhanced antenna breakdown, and signal blackout due to plasma. Plasma-enhanced antenna breakdown is electrical breakdown of the antenna in the presence of a plasma at an altitude where breakdown would not happen without plasma. Blackout due to plasma is complete loss of signal due to high electron density. At staging, these two effects result when flames from an upper-stage engine deflect off the empty lower-stage casing and envelop the antennas. These effects are more pronounced if upper stage ignition occurs before stage separation. Photographs of staging of some rockets have shown the entire vehicle enveloped by flame. During staging, VHF signal blackout periods of the order of 0.5 second have been observed; the length of the blackout periods depends on stage separation time. Although flame envelopment lasts only a fraction of a second, plasma-enhanced antenna breakdown periods of much longer duration have been observed. The reason for this is that once breakdown is initiated, it can be maintained by a lower power level in the same environment or by the same power level in an environment of lower conductivity.

Calculation of Effects

Similar problems will be encountered with the proposed rockets. However, with the exception of length of blackout periods, the magnitude of the problems will be much greater than has been observed because of the size of the boosters and the type of fuel. The amount of flame attenuation depends on electron density and electron-neutral molecule collision frequency. Calculation of these quantities is a very involved process and is subject to many approximations. In Reference 3 Meyer has investigated the effects of certain additives on the electron density of hot air. A lower limit on electron density in the rocket exhaust can be estimated by considering the theoretical exhaust products and extrapolating the results of Reference 3. This procedure gives a lower limit of about 10^{10} electrons per cubic centimeter, but does not take into account any fuel impurities or any exhaust products present in amounts less than 0.01 mole percent (one hundred parts per million) will result in an electron density of greater than 10^{12} electrons per cubic centimeter. Aluminum in the fuel has approximately the same effect since the two ionization potentials differ by less than 1 electron volt. Measurements on solid propellant rockets which use fuels with less aluminum than the fuels proposed here have indicated electron densities of the order of 10^{11} electrons per cubic centimeter (Reference 2). From these considerations a more practical lower limit would appear to be 10^{11} electrons per cubic centimeter—a plasma frequency of about 900 mc. If the collison frequency is less than the plasma frequency, signals below the plasma frequency that are transmitted into the plume will be blacked out.

Effect of Solid Retrorockets

The use of solid retrorockets on the booster stage at staging will greatly increase the communication problem during the staging operation. The effects of the exhaust plume can be decreased somewhat by the following:

1) design and locate antennas so that at least one favorable aspect angle exists at all times;
2) locate antennas as far as possible from flame sources.

These procedures have been used to advantage on many other missiles.

Conclusion

More detailed information is required for a thorough examination of the combustion processes and flow fields. Since the flame attenuation problem has not been solved for a multinozzle rocket, clustered motor boosters will require a considerably larger effort than a single nozzle rocket. Regardless of the configuration decided on, flame attenuation should be studied more closely because it affects such system parameters as flight trajectories, design and location of hardware, and number and location of downrange tracking stations.

REQUIREMENTS FOR FURTHER ANALYTICAL WORK

A clustered solid-propellant motor stage wherein normal propellant batch-to-batch variations in ballistic properties are ascribed to the performance of the full motors places an unrealistically severe requirement on the thrust-vector control system. There was no opportunity in this study to undertake a statistical probability analysis of batch and motor performance variations, as well as an analysis of the cumulative effects in the stage of individual motor thrust misalignment. These studies should be undertaken early in any further vehicle preliminary design efforts.

References

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5. Tynas, G. and Held, L., "On the Propagation of Electromagnetic Waves Through Anisotropic Layers." Trans. I.R.E. on Antennas and Propagation. Vol. AT75 Special Supplement Dec. 1959.
6. Space Technology Laboratories Report GM-60-0000-13732 (S) (Boeing Central Library File No. C755-GM-60-0000-13732 (S)
7. Meyer, Fred, "Effect of Various Additives on the Electron Density of Hot Air in Thermodynamic Equilibrium," document D2-9541, March 1961, Physics Technology Dept., Aero-Space Division, The Boeing Company.

3. STRUCTURES

This section outlines the structural design criteria of the Phase II study, the materials selected, the structural load analyses performed, the first-mode bending frequencies determined, and the vehicle design considerations.

DESIGN CRITERIA

Factors Of Safety

Ultimate Factory Of Safety = 1.40[1]

The ultimate factor of safety is the ratio of the design ultimate load on a structure to the limit load.

Yield Factory Of Safety = 1.10[1]

The yield factor of safety is the ratio of the design yield load on a structure to the limit load.

Note: Where pressurization contributes to the load carrying capacity of a structure, a limit and ultimate factor of 1.0 was used on the minimum operating pressure for the condition being checked.

Limit Load

Limit load is the maximum calculated load which will be experienced by the structure under the specified conditions of operation.

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[1] See references at end of this section. Ref. A, 4.3.3 gives yield 1.1 and ultimate 1.4; Ref. B, 15.3 gives yield 1.1 and ultimate 1.35.

Table IVA3-2

	Tank Weight (% of Steel Tank)	Tank E I (% of Steel Tank)
Aluminum	119	112
Steel	100	100
Titanium	97.2	89.5
Fiberglass	76.8	44.4

Although the titanium considered (annealed) has good fracture toughness it is very susceptible to contamination during welding. The problems of using fiberglass in the required thicknesses are not clearly understood.

On the basis of the previous information it appears that titanium and steel will be the better choices of presently available materials. To evaluate the fracture toughness problem of steel motor cases, fracture mode transition values are shown in Figure IVA3-1. Data in the 200,000-psi stress range is limited but there is sufficient information to outline the considerations necessary for the selection of a heat-treat level in high-strength steel. As indicated, in the efficient stress ranges the case material will be operating in the flat or brittle fracture range due to the required case thicknesses. The choice of heat-treat level is, therefore, strongly related to allowable rejection rates and inspection techniques.

Stress risers such as surface cracks and inclusions must be closely controlled. Figure IVA3-2 demonstrates the physical size of surface flaws which will produce case failure and their relationship to heat-treat level. Although surface flaws do not present the inspection problems of internal flaws, they are discussed from the standpoint of simplicity.

It can be seen that, at the material working stress, a .052-inch-deep surface crack will produce failure in a 220,000-psi ultimate material and a .082-inch-deep crack will fail 200,000-psi material. The detectable crack size must be smaller than these values, however, to ensure a safety margin between the existing cracks and the cracks which produce failure at the working stress level. The

Weld Efficiency = 90%

The weld efficiency is the strength of the welded joint expressed as a percentage of the strength of the base metal.

MATERIAL SELECTION

Motor Case Materials

One of the basic criteria for material selection was short lead time for fabricated cases. To comply with this ground rule, material types and stress levels must reflect state-of-the-art capabilities. From this standpoint, steel and aluminum are the more logical choices—steel being the most widely accepted in solid motor case fabrication.

Table IVA3-1 presents a summary of possible material choices and estimated practical stress levels. Based on the tabulated strength-to-weight ratios, it is seen that fiberglass is the most attractive choice with titanium and steel next.

Table IVA3-1

	F_{tu}	ρ	$F_{tu}/\rho \times 10^3$	E
Aluminum	59,500	.1	595	10×10^6
Steel	200,000	.283	708	30×10^6
Titanium	120,000	.164	732	16.1×10^6
Fiberglass	60,000	.065	924	4×10^6

However, as indicated in Table IVA3-2, other factors must be considered. Tank weight and stiffness relative to a strength-designed steel tank are shown. From the standpoint of stiffness, the steel tank is first choice on an equal weight basis with aluminum and titanium next. An additional factor to be considered is the fracture toughness or "forgiveness" of the various materials. It can be shown that both steel and aluminum will be in the plane strain or brittle fracture region due to the large case thicknesses necessary.

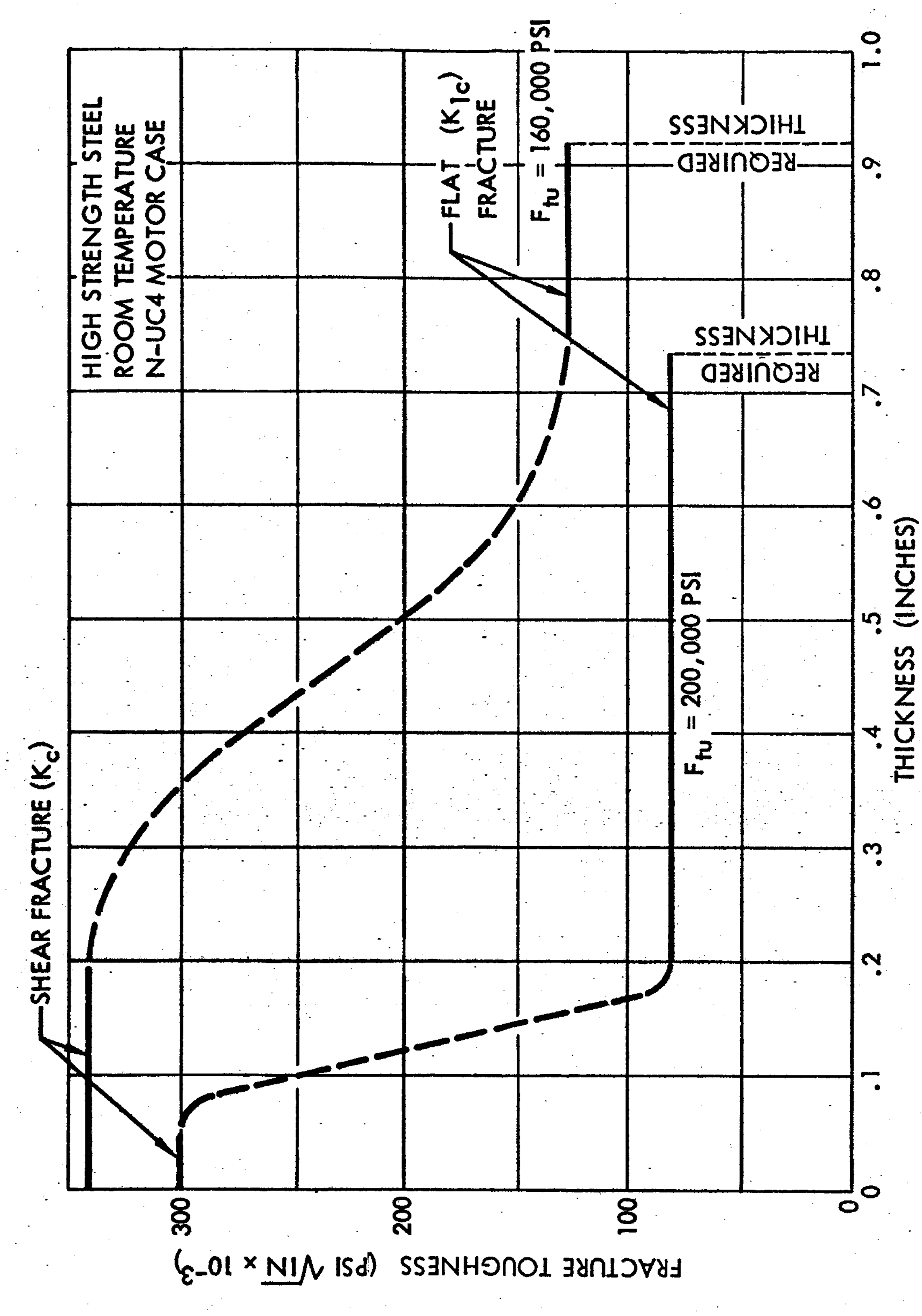


Fig. IV A3-1 FRACTURE TOUGHNESS VS THICKNESS

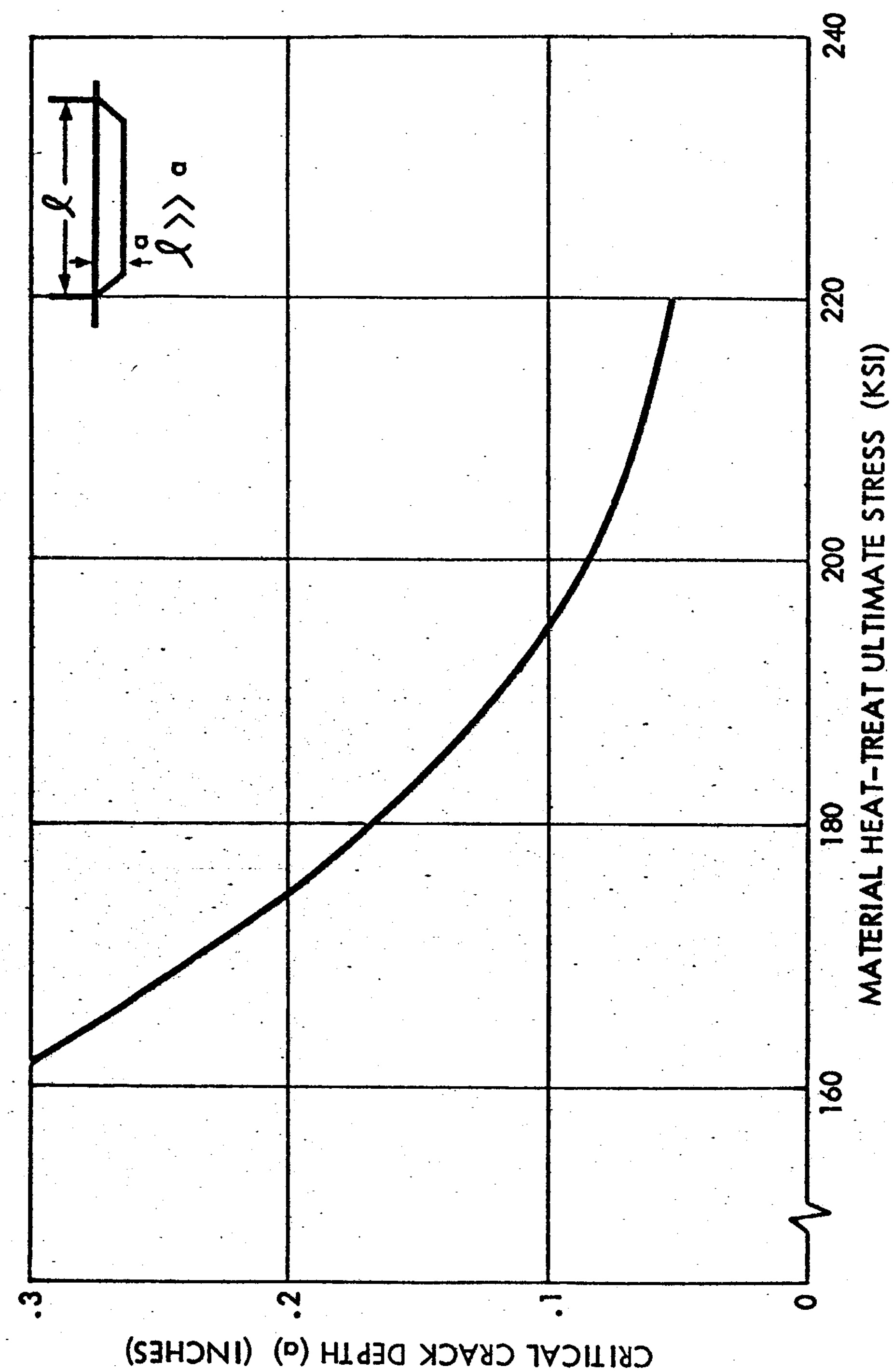


Fig. IV A3-2 CRITICAL CRACK DEPTH IN FLAT FRACTURE RANGE margin between these conditions is related to crack growth rate, which is a function of both time and cyclic load application. The crack size must be large enough to be detected but small enough so as not to grow to critical length within the life expectancy of the part. To ensure that the flaws in the final case are not larger than the minimum acceptable value, a proof test must be made. Selection of a heat treat which is too high to permit detection of flaws by reasonable inspection techniques will result in a large number of catastrophic proof test failures.

Based on measured fracture toughness data, the commercially available low-alloy high-strength steels, heat treated to approximately 200,000 psi ultimate, appear compatible with reasonable inspection techniques. For this reason it was selected as the baseline material for this study.

Looking to the future, the high-nickel steels show considerable promise. Preliminary fracture toughness data indicate good toughness at strengths approaching 300,000 psi. With additional investigation of brittle fracture toughness and fabrication characteristics, it is hoped that these higher strengths will be realized.

Also, the potential use of titanium cannot be ignored. Despite its relatively high material cost, the use of this material in the annealed condition would eliminate requirements for heat treatment. Although on a preliminary basis this material appears competitive and probably better than 200 ksi low-alloy steel, it could not be justified for this study because of lack of good fracture toughness data and large case fabrication information.

Cryogenic Tankage Material

Weldable aluminum material allowables were used for cryogenic tankage. Table IVA3-3 summarizes the material properties at room temperature and at cryogenic temperatures.

Table IVA3-3

CRYOGENIC TANKAGE MATERIAL

	70°F	-297°F
Ultimate Strength	59,500 psi	74,000 psi
Yield Strength	42,500 psi	52,000 psi

Interstage and Miscellaneous Unwelded Material

High-strength aluminum material allowables were used for interstages and miscellaneous structure. The material ultimate strength was 70,000 psi and the yield strength was 62,000 psi.

LOAD ANALYSES

Flight Loads

The loads analysis consisted of the determination of a reference bending moment calculated for the 30,000-pound-payload vehicle by a digital machine solution of the equations of motion. Based on this reference moment, other vehicle bending moments were calculated by instantaneously trimming the vehicles to the angle of attack associated with the reference moment.

Reference Bending Moment

The reference bending moment due to wind shear and gust was calculated with a digital machine program. This program computes time varying responses and loads of the vehicle due to a prescribed forcing function. It utilizes a continuous simulation, or time varying description, of the vehicle parameters and aerodynamic environment.

Forcing Function—The Avidyne wind profile (Reference C) shown in Figure IVA3-3 was selected as the wind-shear criteria. The critical altitude is defined as the altitude at which $(q/V)\ W_s \sin \gamma$ is maximum, where q is dynamic pressure,

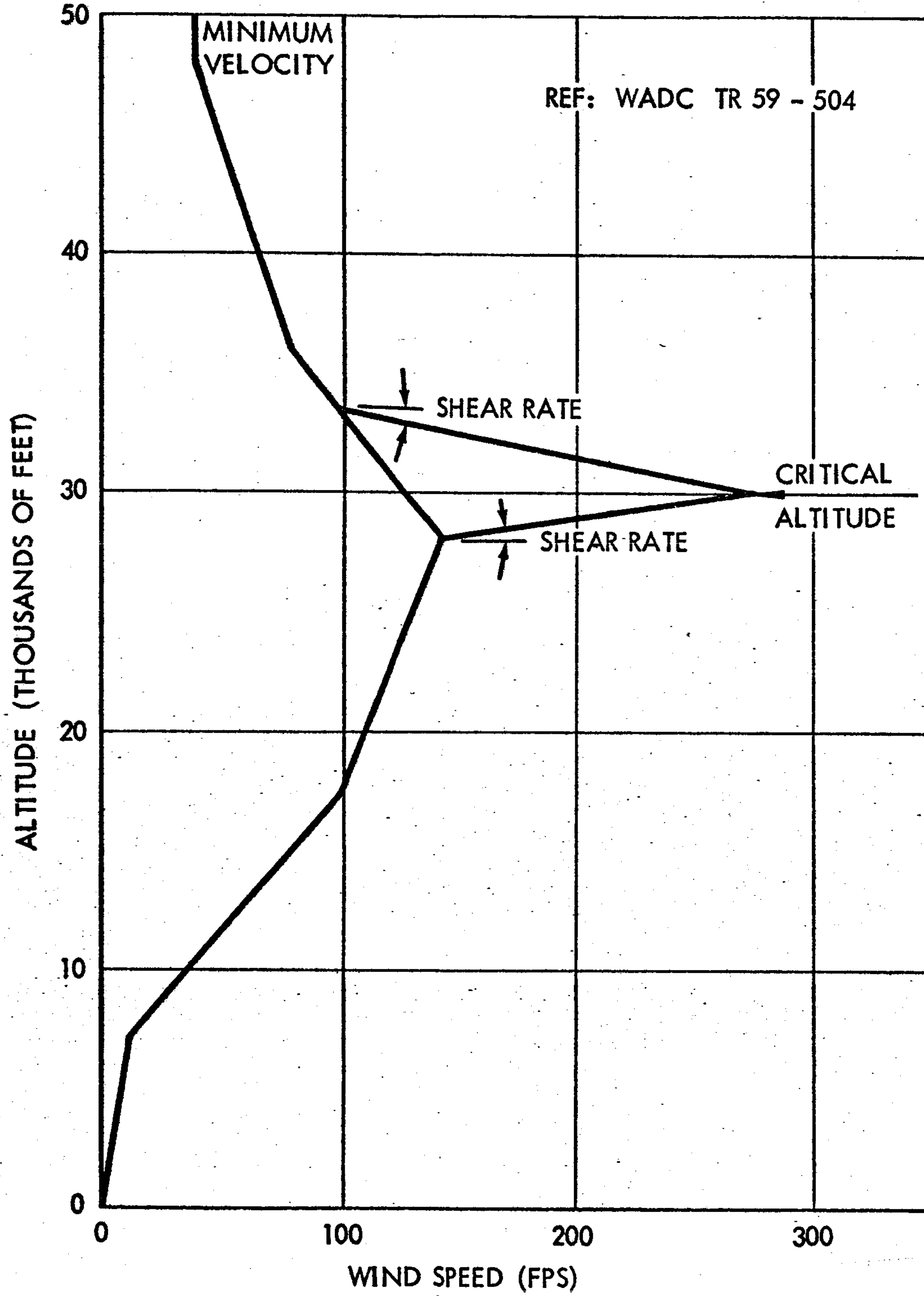


Fig. IV A3-3 AVIDYNE WIND PROFILE

V is forward velocity, W_s is the wind velocity and γ is the flight path angle. The shear rate of the spike is 0.05 feet per second per foot of altitude. Bending moments caused by a 20-fps critically phased gust (of 1-cos shape) were added directly to maximum wind shear loads to obtain total bending moments. The gust frequency was selected to cause maximum vehicle bending moments.

Aerodynamic Environment—The aerodynamic environment is defined by the trajectory of Section IVA1, Figures IVA1-6 and IVA1-7. Dynamic-pressure forward velocity and flight-path angle are the required variables.

Vehicle Parameters—The vehicle parameters required are vehicle mass distribution, flexibility, lift distribution, and control system responses.

Lift distribution was obtained through the application of second-order shock-expansion theory. The control system utilized pitch attitude and pitch rate control.

Vehicle Trim Moments

Wind-shear loads were obtained by instantaneously trimming the vehicles to an angle of attack. This involves placing the vehicle in equilibrium with the aerodynamic loads produced at the angle of attack prescribed by the reference bending-moment condition. The effects of gust and flexibility were proportioned on the basis of the reference moment. An angle of attack of 6 degrees was obtained from the reference calculation. Because Phase I work (Reference D) showed that angle of attack was relatively constant for the two-stage vehicles studied, a constant 6-degree angle of attack was used for Phase II vehicles.

Combined Flight Loads

Flight bending and associated axial loads were combined as an equivalent axial load. Equivalent axial load is defined as that axial load which produces the same compressive wall stress as the maximum compressive wall stress resulting from any combination of bending moment plus axial load.

Ground-Wind Loads

Ground-wind criteria was taken from Reference E. A steady-state wind of 40 mph plus 20-mph gusts at a height of 10 feet above ground level was used as the design reference value. The low level wind profile based on this value is shown in Figure IVA3-4.

The dynamic response of the vehicles, characterized by a dynamic magnification factor, was obtained from Reference F. A structural dynamic magnification factor of 1.65 was chosen for the vehicles studied and applied to the gust portion of the load. Figures IVA3-5 and -6 show a typical ground-wind bending moment distribution based on a drag coefficient of .42. The vehicle was required to withstand ground wind, empty or flight ready, with propellant tanks unpressurized.

Results of Load Analyses

Bending moment distributions for the study vehicles are shown in Figures IVA3-5 through -10. The axial load distributions associated with these vehicles are shown in Figures IVA3-11 through -14. The largest portion of the upper stage, the LH_2 tank, was designed by consideration of ground wind loads at the tank midpoint in the 100,000-, 180,000-, and 350,000-pound-payload vehicles. The design condition at the aft end of the LH_2 tank was the flight bending load for all vehicles. The 30,000-pound-payload vehicle was designed by flight bending loads at the LH_2 tank midpoint. The interstage shell was designed by flight bending loads in the 30,000- and 100,000-pound-payload vehicles and by burnout loads in the 180,000- and 350,000-pound-payload vehicles.

VEHICLE FIRST-MODE BENDING FREQUENCIES

The first-mode bending frequencies of the study vehicles are shown in Table IVA3-4.

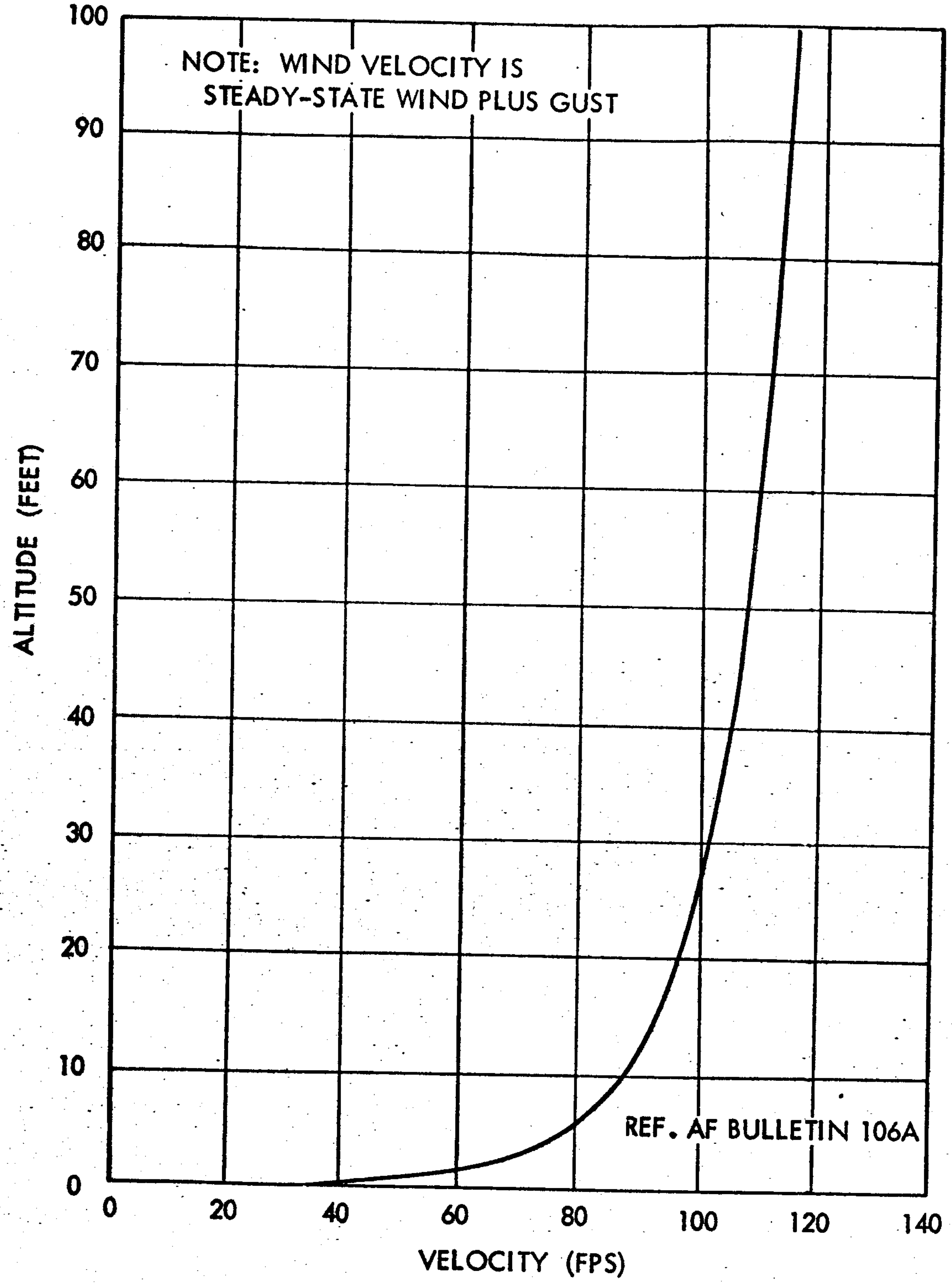


Fig. IV A3-4 LOW-LEVEL WIND PROFILE
WIND VELOCITY VS. ALTITUDE

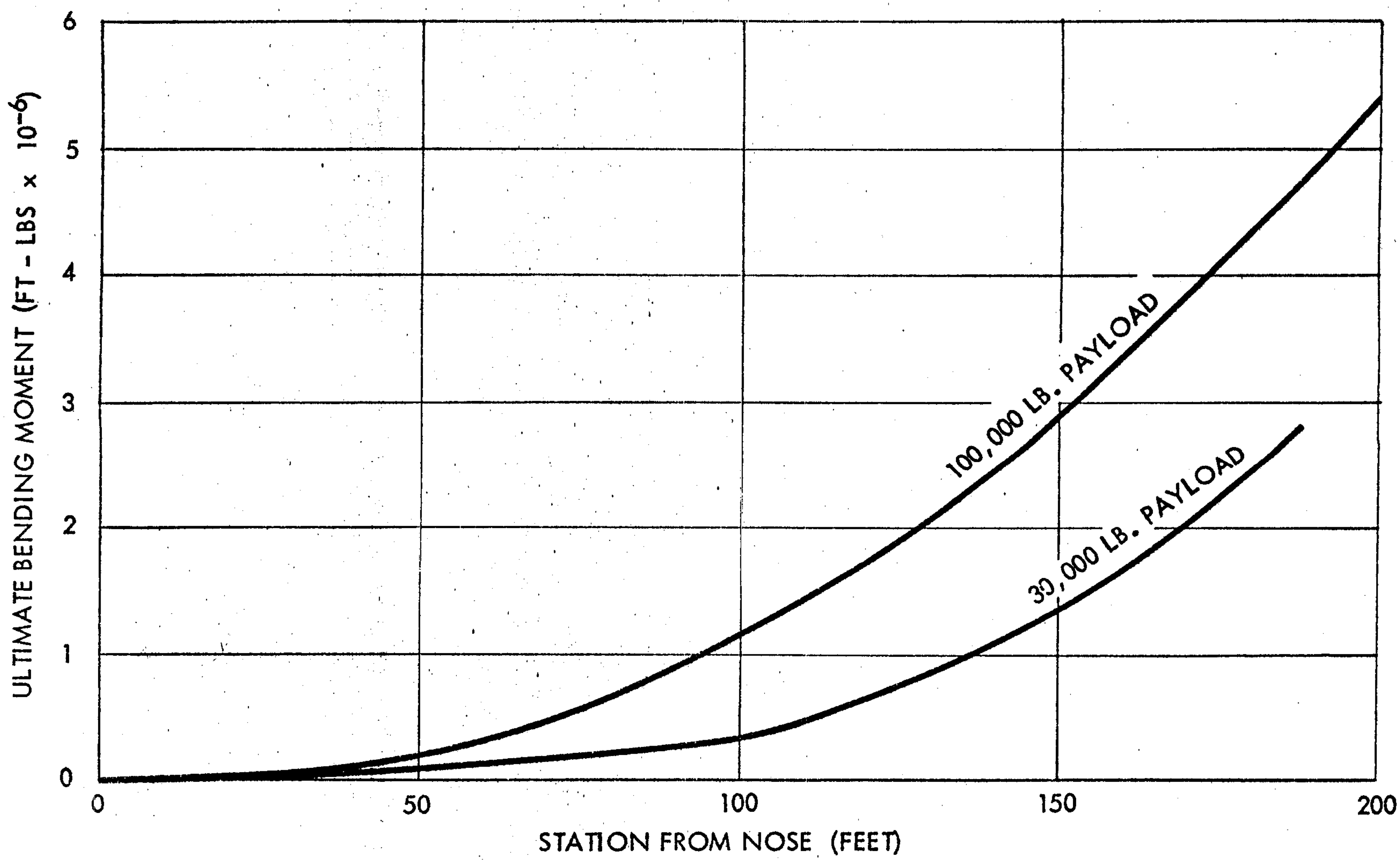


Fig. IV A3-5 GROUND WIND BENDING MOMENT 30,000- & 100,000-LB. PAYLOADS

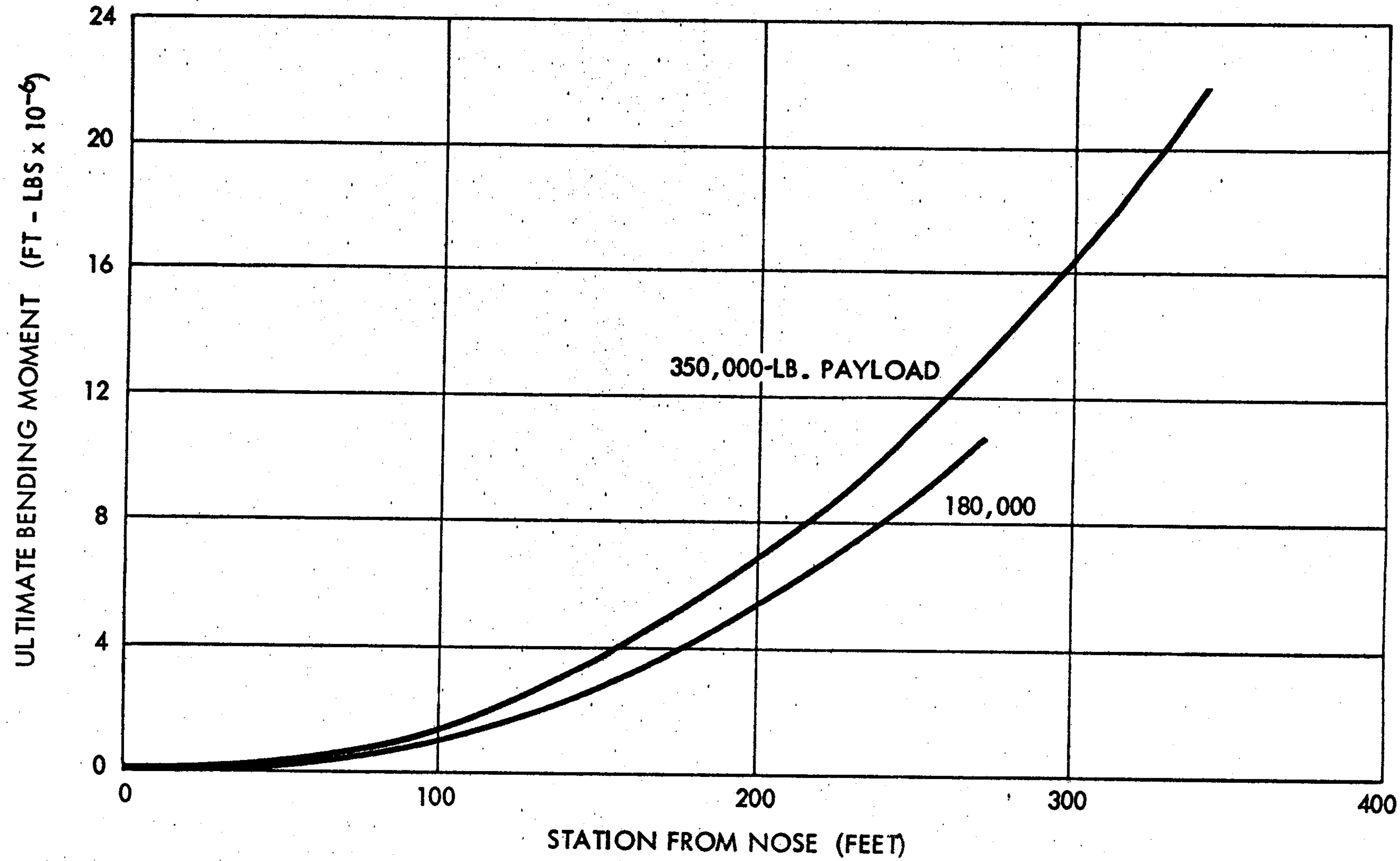


Fig. IV A3-6 GROUND-WIND BENDING MOMENT 180,000-& 350,000-LB. PAYLOADS

NASA SOLID BOOSTER STUDY

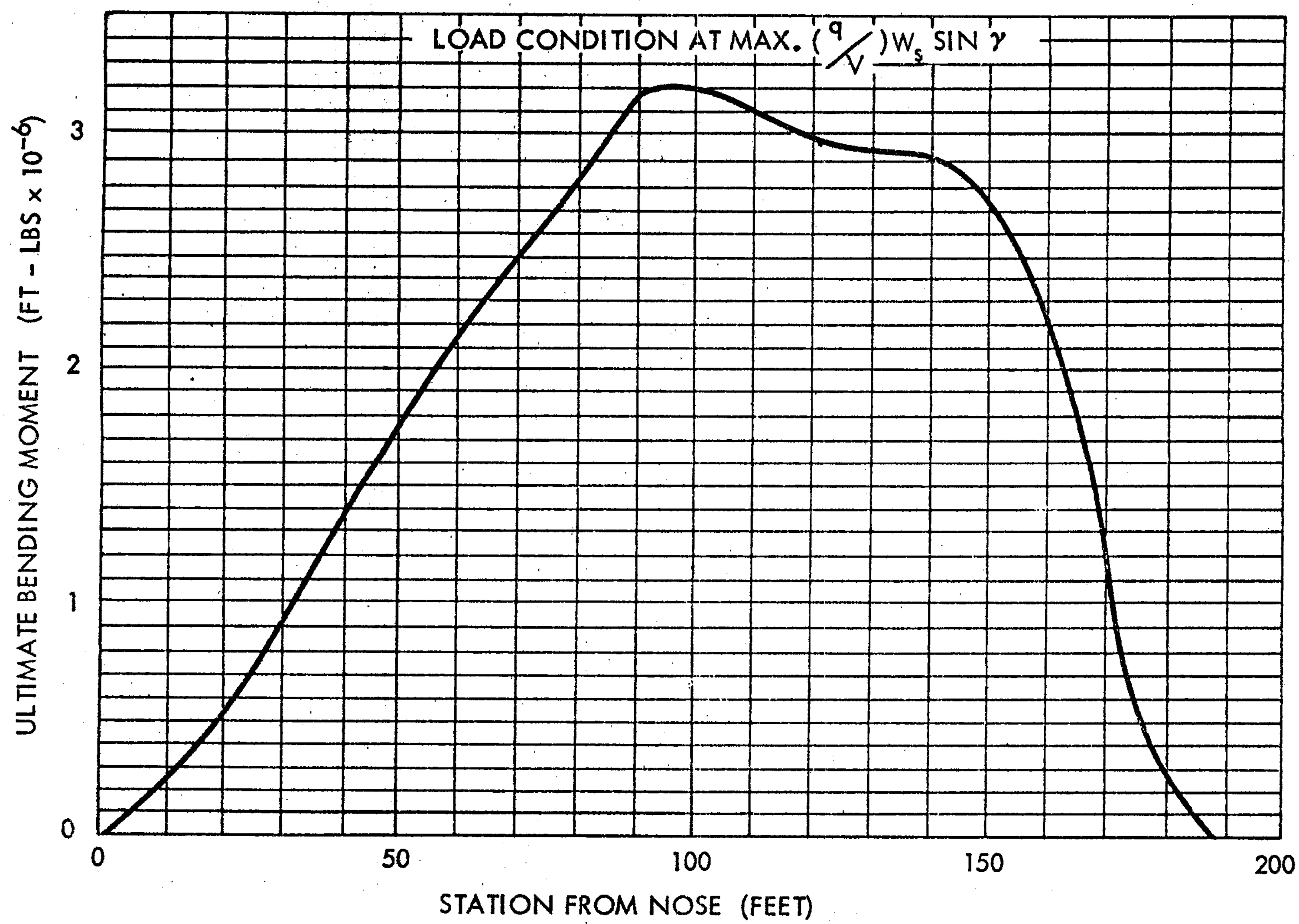


Fig. IV A3-7 FLIGHT BENDING MOMENT CONFIGURATION I SI 30,000-LB. PAYLOAD
NASA SOLID BOOSTER STUDY

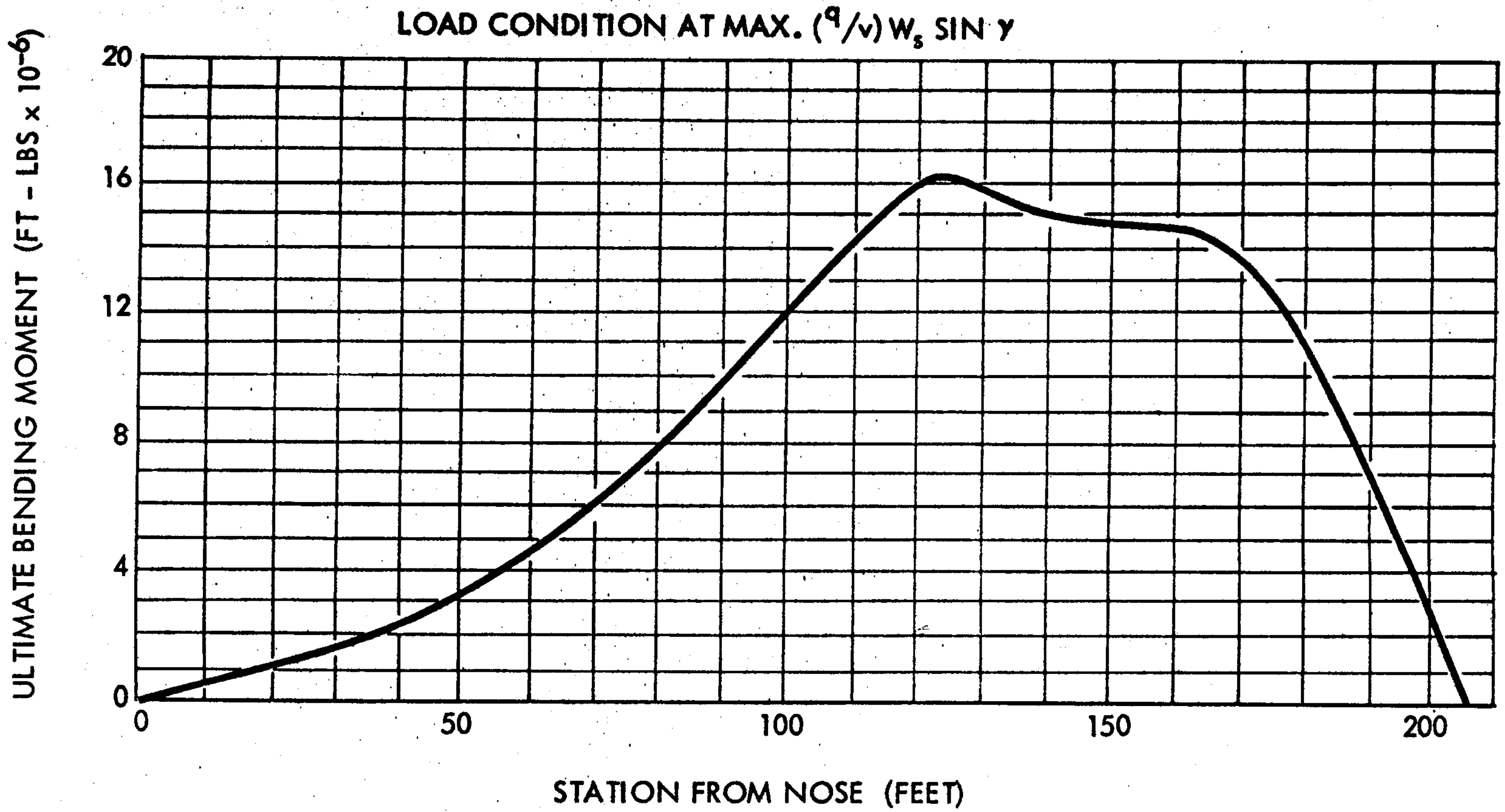


Fig. IV A3-8 FLIGHT BENDING MOMENT CONFIGURATION 3-SC4 100,000-LB. PAYLOAD
NASA SOLID BOOSTER STUDY

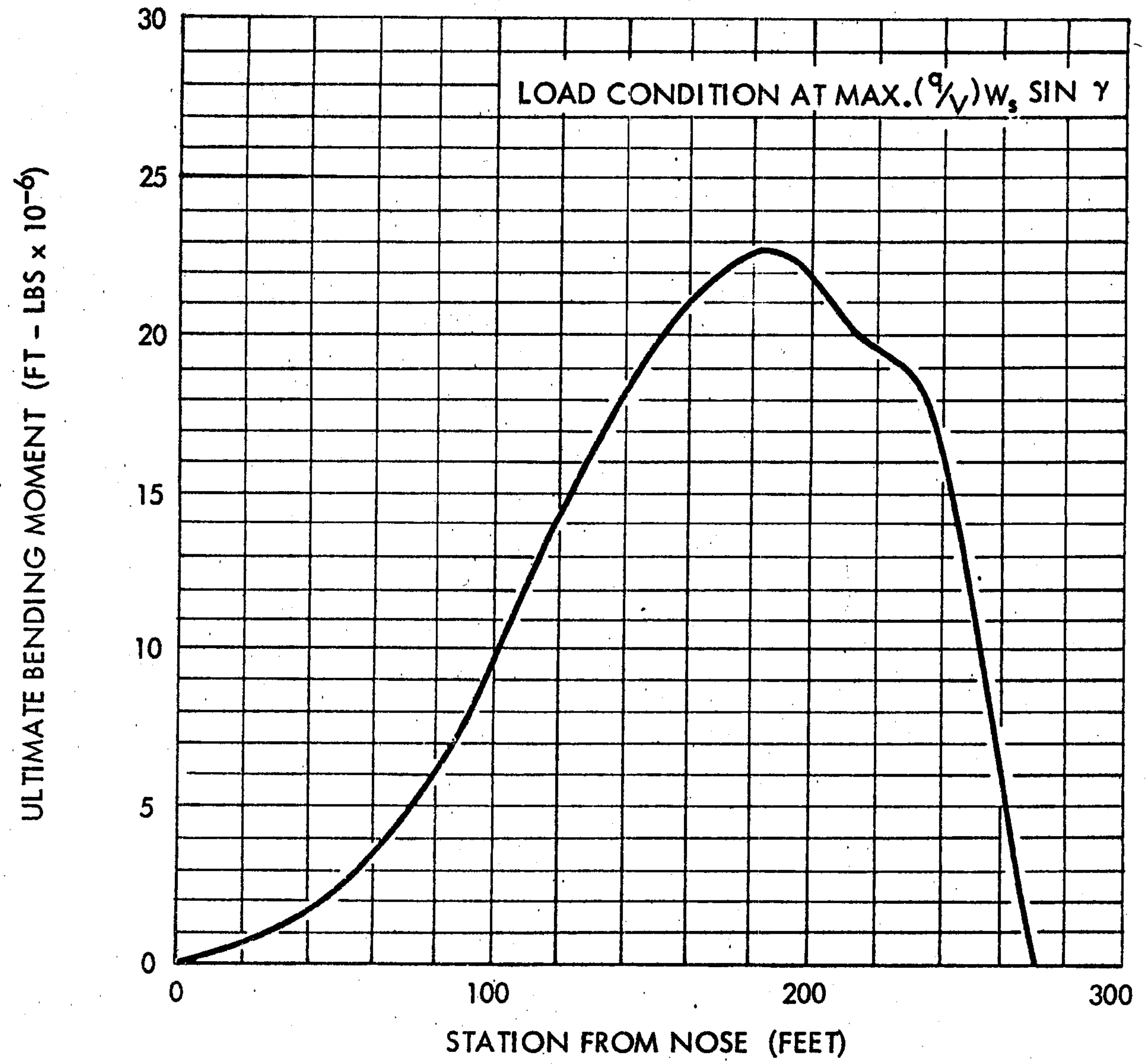


Fig. IV A3-9 FLIGHT BENDING MOMENT CONFIGURATION 4-UC4 180,000-LB PAYLOAD
NASA SOLID BOOSTER STUDY

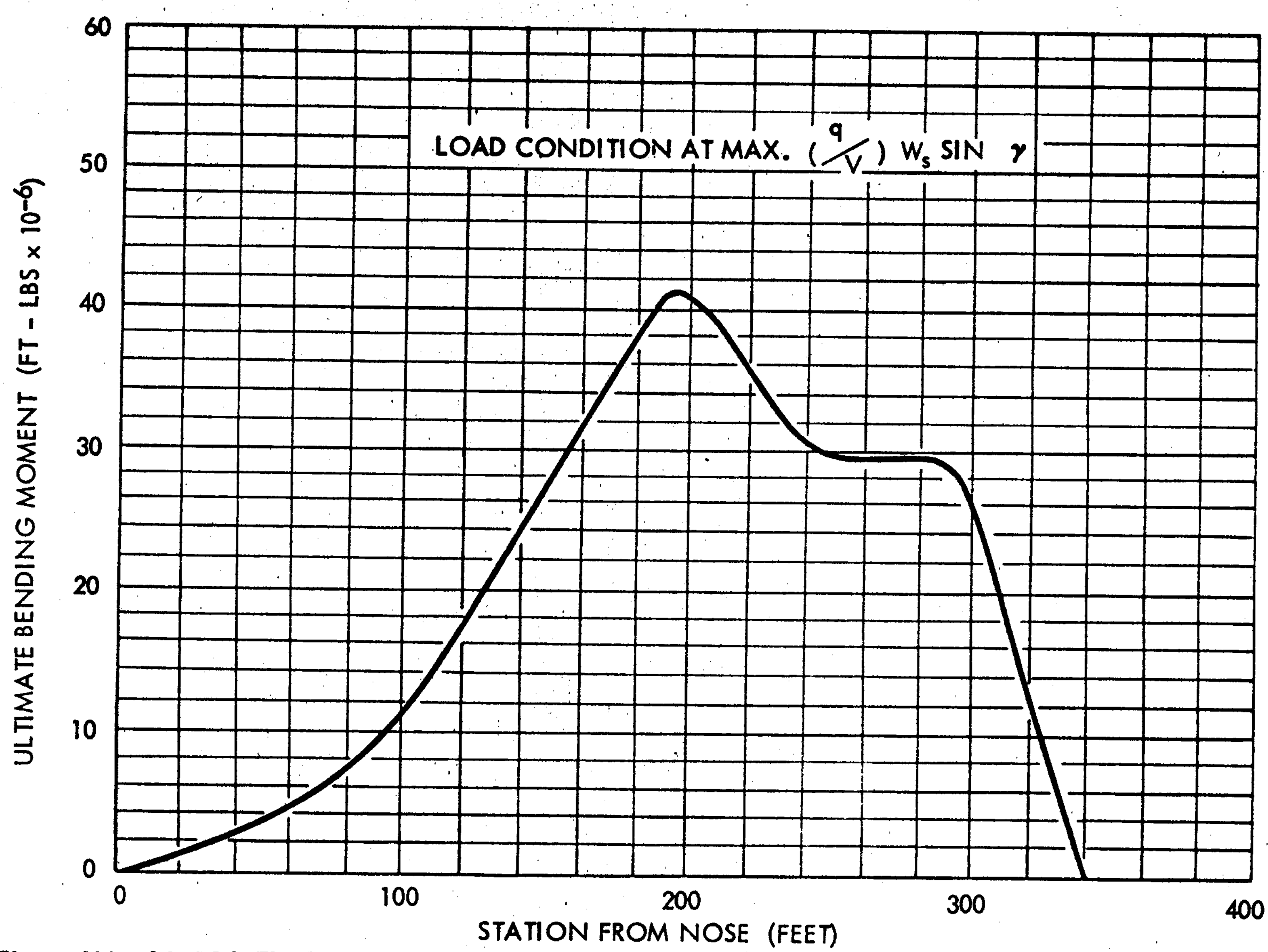


Fig. IV A3-10 FLIGHT BENDING MOMENT CONFIGURATION N-OC4 350,000 LB. PAYLOAD

NASA SOLID BOOSTER STUDY

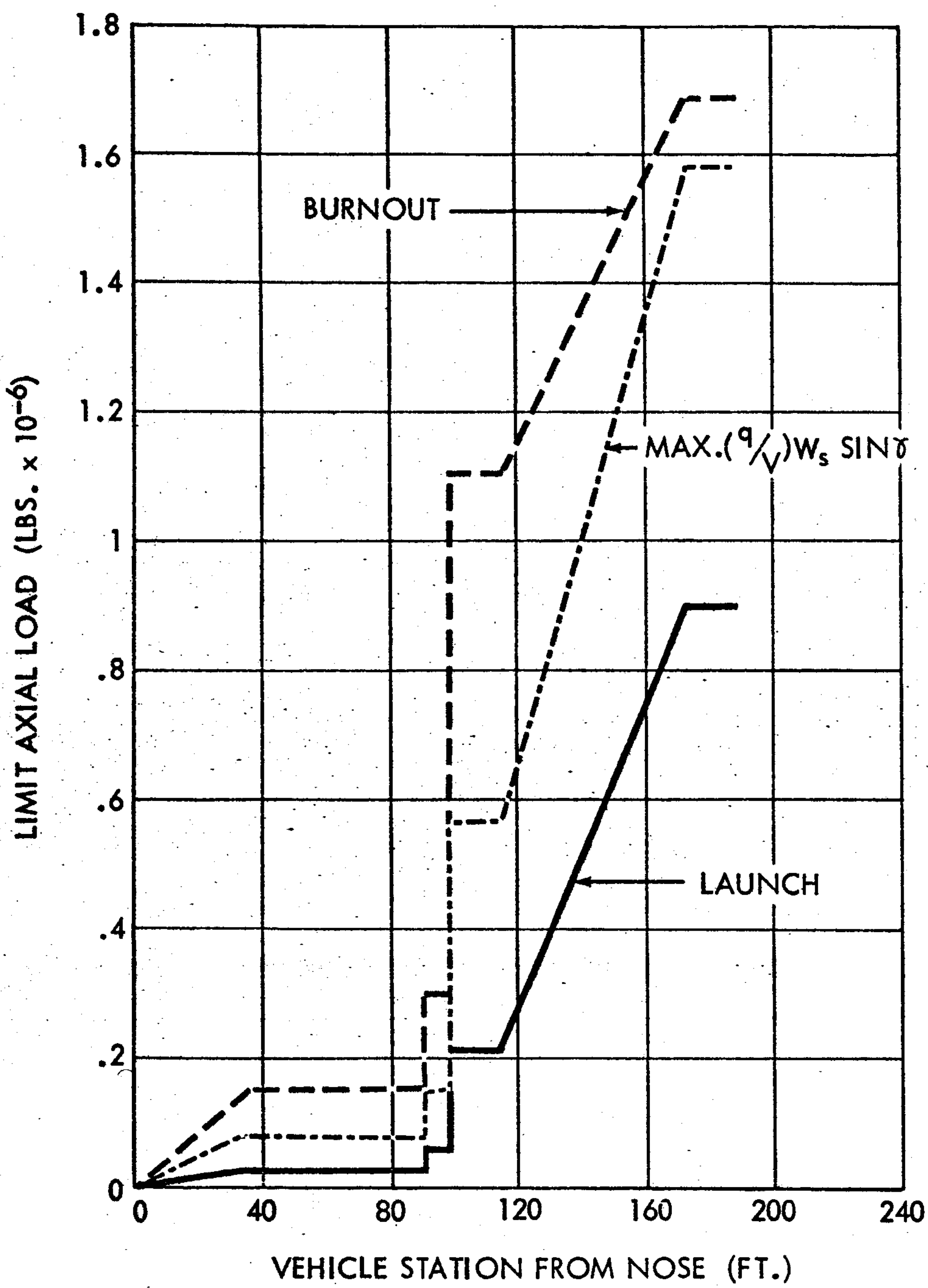


Fig. IV A3-11 I-SI VEHICLE AXIAL LOADS

2-STAGE CLUSTERED VEHICLE 30,000 LB. PAYLOAD

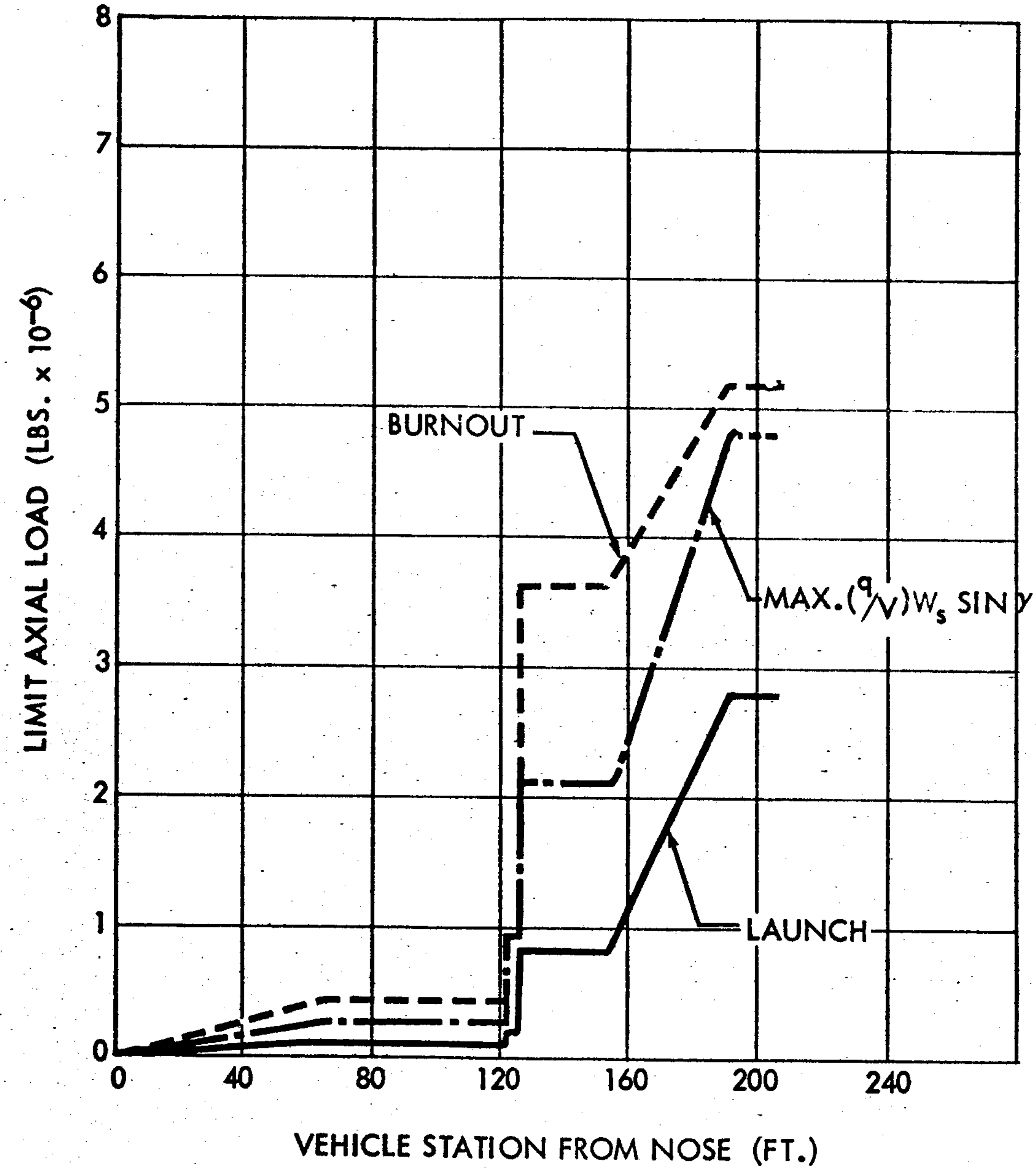


Fig. IV A3-12 3-SC4 VEHICLE AXIAL LOADS
2-STAGE CLUSTERED VEHICLE 100,000 LB. PAYLOAD

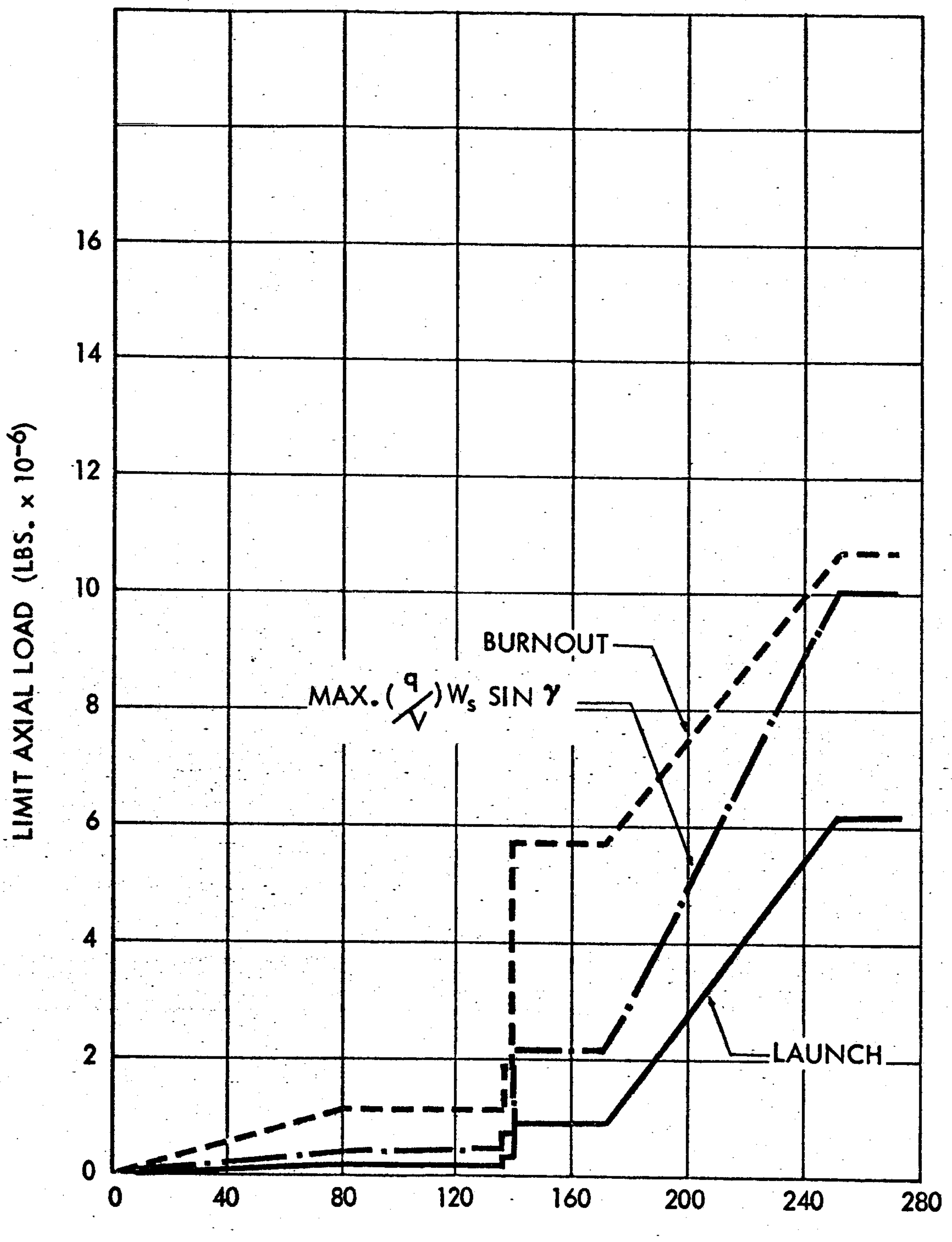


Fig. IV A3-13 4-UC4 VEHICLE AXIAL LOAD
2-STAGE CLUSTERED VEHICLE 180,000 LB. PAYLOAD

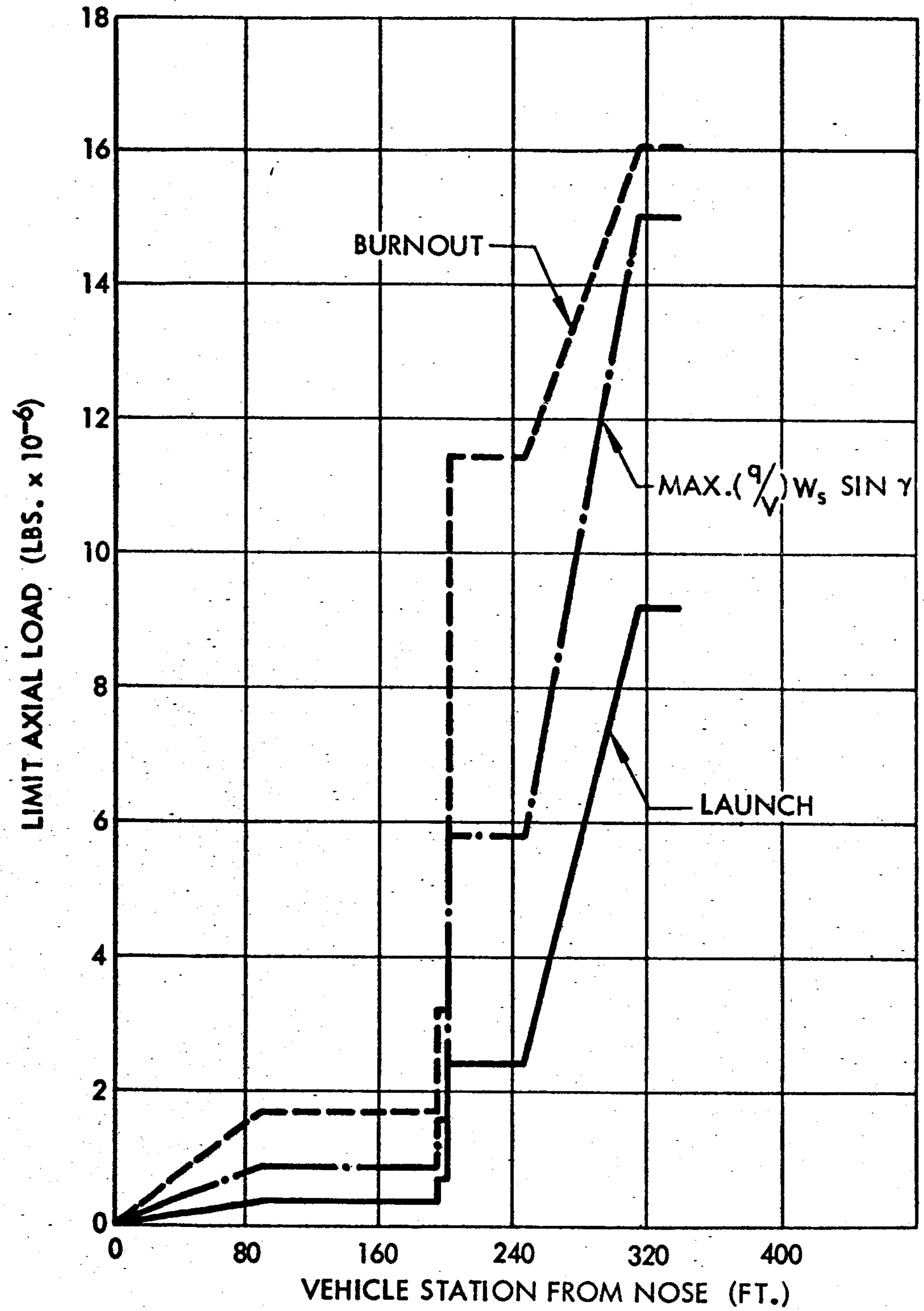


Fig. IV A3-14 N-UC4 VEHICLE AXIAL LOADS
2-STAGE CLUSTERED VEHICLE 350,000-LB. PAYLOAD

Table IVA3-4:

VEHICLE FIRST-MODE BENDING FREQUENCIES

Vehicle	Frequency (cps)
30,000-pound Payload (single)	.98
100,000	1.17
180,000	.73
350,000	.81

The first-mode bending frequency was determined through use of a digital program that determined bending-mode shapes, frequencies, and generalized mass for a variable stiffness beam that may have concentrated masses attached. The frequencies and mode shapes are determined by a Myklestad method of solution of the pertinent differential equations.

The tabulated frequencies are based on the assumption of a rigid-cluster structure. To evaluate the reduction in first-mode bending frequency due to increased flexibility in the interstage region, the frequency was obtained for the above vehicles with an interstage stiffness of one-fourth of the original value. Results of this analysis are shown in Table IVA3-5.

Table IVA3-5:

VEHICLE FIRST-MODE BENDING FREQUENCIES

Interstage Stiffness One-Fourth Of Nominal

Vehicle	Frequency (cps)	% Reduction From Nominal
100,000-pound Payload	1.09	8.0
180,000	.67	7.4
350,000	.72	12.0

The interstage flexibility effect on first-mode bending frequency is of the order of 10 percent for the factor of four reduction. Therefore, the interstage stiffness of these vehicles does not appear to have a large effect on the first-mode bending frequency.

Two methods of increasing the first-mode frequency were investigated: the first stage stiffness of a Saturn C-1 class vehicle was varied; and the fineness ratio of the 30,000-pound-payload vehicle was reduced. The effect of varying first stage stiffness is shown in Table IVA3-6.

Table IVA3-6:

VARIATION OF FIRST-MODE BENDING

Frequency With First-Stage Stiffness

Saturn C-1 Class Vehicle

First Stage Stiffness Multiplying Factor	Percent Increase In First Mode Frequency
1	0
1.5	5.7
2.0	8.6
∞	20.8

A maximum increase of 20.8 percent in the first-mode bending frequency can be obtained by making the first stage of this vehicle infinitely stiff. It is concluded that vehicles of this size are not greatly affected by first-stage stiffness increase.

The effect of fineness ratio was investigated by reducing the fineness ratio of the 30,000-pound-payload vehicle from 13.6 to 9.2. This increased the first-mode frequency from .98 cps to 1.52 cps—an increase of 55 percent.

It is concluded that vehicle fineness ratio is the important variable in the improvement of first-mode bending frequency. Significant increases in first-mode frequency are difficult to obtain by increasing the stiffness of the first stage or interstage.

VEHICLE STRUCTURAL DESIGN

Structural design concepts and analysis procedures common to all study vehicles are discussed below.

First Stage

Motor Cases

Nominal Chamber Pressure = 800 psia—The nominal chamber pressure is the pressure to which the tank is subjected under steady-state conditions in service operations.

Limit Chamber Pressure = 984 psia—Limit chamber pressure is the maximum pressure that will be experienced by the tank under the specified conditions of operation. This includes the grain ambient temperature variation (70°F ± 30), 3.6 percent of nominal; programed instantaneous burning area overpressure (n = .3), 7.2 percent of nominal; variations in burning rate and other formulation properties, allowance for cracks, voids,and other grain irregularities, pressure drop along grain, 11 percent of nominal. The total allowance equals 23 percent.

Ultimate Chamber Pressure = 1378 psia—Ultimate chamber pressure is the limit chamber pressure multiplied by the ultimate factor of safety (1.4).

Case Thicknesses—The case thicknesses were computed from the membrane stress equation:

$$t = \frac{PR}{\sigma K}$$

where

P = Internal Pressure = 1378 psia

R = Tank Radius

σ = Material Stress Level = 200,000 psi

K = Weld Efficiency = .90

The resulting case thicknesses were 0.612 for the 160-inch-diameter cases and 0.735 for the 192-inch-diameter cases.

In the event that heat-treat capability will not be available for completely fabricated unitized cases, an alternative process of utilizing as-welded circumferential joints was considered. Land areas can be provided in the heat-affected zone to allow the local material to operate in the as-welded condition. The thickness of the land area will be $\frac{200,000 \text{ psi}}{111,000 \text{ psi}}$ x nominal or 1.10 for the 160-inch-diameter case and 1.32 for the 192-inch-diameter case.

Case Axial Loads—Motor case flight loads were computed for the pressurized condition. The loads were assumed uniformly distributed over 100 degrees of the barrel section. A shear lag angle of 20 degrees was used to determine the redistribution at the tank head juncture. The load distribution at the head juncture was assumed to be nonuniform with a maximum value 50-percent greater than the uniform distribution. The allowable load was defined as that which would produce zero wall stress at a tank pressure of 800 psi. The additional compressive capability of the case was not included. Vehicle axial loads and case bending loads are given in Load Analyses above.

The maximum load condition for the 160-inch tanks was in the 180,000-pound-payload vehicle that had a margin of safety of .83. For the 192-inch tank the margin of safety was .29.

Unpressurized motor case strengths were determined for the free-standing ground condition and for the fully loaded ground-handling condition.

Cylinder buckling loads were based on a statistical treatment of nondimensionalized cylinder buckling data applied to the pressure designed motor cases. Ninety-percent probability, 95 percent confidence values were used.

Buckling Stress Equation:

$$\frac{F}{E} = K \frac{t}{R}$$

Where:

F	=	Allowable Stress—psi
E	=	Young's Modulus—psi
t	=	Skin Thickness—inch
R	=	Cylinder Radius—inch
K	=	Cylinder Buckling Constant

The ground-wind load conditions are given in Load Analyses above. The vehicles were analyzed for the flight ready condition. A summary of safety margins for the ground-wind condition is shown in Table IVA3-7.

Table IVA3-7

MOTOR CASE BUCKLING

Ground Wind Loading of Unpressurized Motor Cases

Vehicle	Margin of Safety
30,000-pound Payload	.83
180,000-pound Payload	.57
350,000-pound Payload	.475

The margins of safety indicate that the pressure-designed motor cases are adequate for the unpressurized load conditions.

The ground handling condition was analyzed for the unitized motor cases supported only at the case skirts, and bending moments were determined for a 2-g loading condition. In the present ground-handling procedure, horizontal support will be required only for the procedure in which the case is turned from the base-up to the base-down position. This would be classified as special handling and a 2-g load factor was assumed for the lateral direction. The margins of safety for this condition are shown in Table IVA3-8. Grain distortion effects are not included.

Table IVA3-8

MOTOR CASE BUCKLING

Loaded Unitized Cases—Simple End Supports—2-g Load Condition

Vehicle	Margin of Safety
100,000-pound Payload	1.93
180,000-pound Payload	-.29
350,000-pound Payload	-.57

The 180,000- and 350,000-pound payload motor cases will require additional support for the ground handling environment to prevent case buckling.

Motor Case Joints—A motor case segmented-joint concept based on demonstrated performance was chosen for this study. Several joint concepts under development by solid motor manufacturers have been fabricated and have demonstrated production assembly capability. The joint concept used in this study (Figure IVA3-15) consists of a single lip inserted between two flanges and anchored by a tapered pin. Also shown is the welded joint concept used in unitized cases that are not heat treated after welding. Forged rings are welded to the motor case sections and heat treated. The ring sections are then welded together, stress relieved, and left in the as-welded condition. In Motor Case Thicknesses above, ring size requirements are discussed.

Because the axial and circumferential loads which must be carried through mechanical joints are equal to the loads carried through the basic case, the amount of material resisting deformation must be at least as great as the basic case. Therefore, if there is no mechanical movement of the joint, either axially or by interface slippage, the stiffness of the mechanically joined tanks should be nearly equal to the unitized tanks. As stated in Flight Loads above, there is a minimum margin of safety of .29 before side wall compression occurs in the vehicles studied. This means that there should not be a mechanical separation in the axial direction during flight. Side slippage was investigated using a coefficient of friction of .42 (Reference G). The resulting margin of safety before slippage was 19.6. Therefore, any deflection of the first-stage motor case must be due to material deformation.

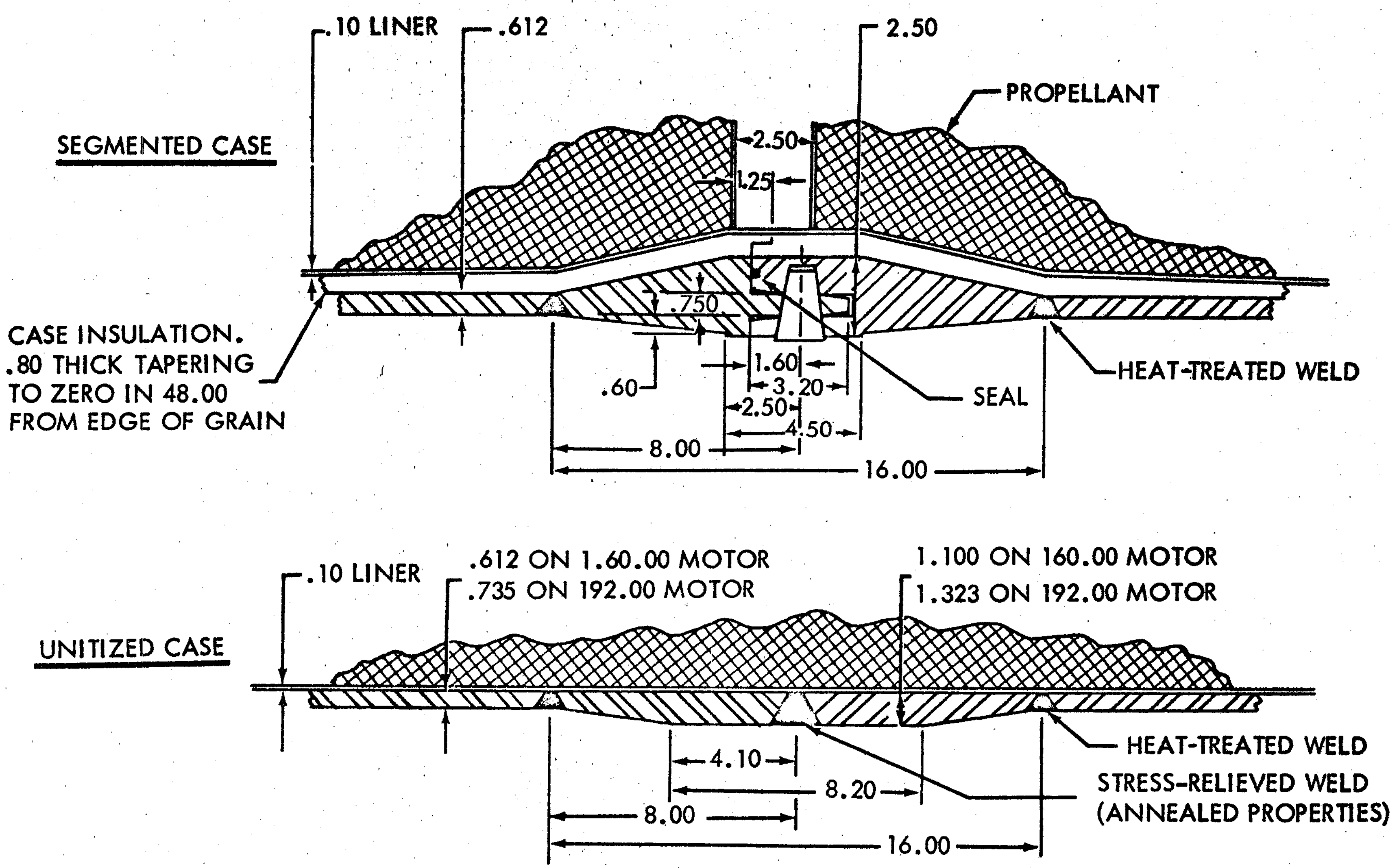


Fig. IV A3-15 SOLID MOTOR CASE JOINTS

Cluster Structure

This section contains the design and analysis of the clustering concept used on the tandem staged study vehicles.

Design Philosophy—Cluster structure concepts are herein classified into four general categories: 1) cases fixed at both ends, 2) cases fixed at one end only, 3) cases shear-tied together, and 4) cases supported by an external framework. A detailed parametric investigation was not within the scope of this study. Therefore, one general category was chosen based on qualitative factors and design concepts were varied within this area. Based on current best estimates of relative weight and development risk, category 2), cases fixed at one end, were chosen. This method has several advantages. Differential expansion can occur between tanks and the inherent strength of the motor cases is utilized. Concentrated loads on the motor cases are eliminated. One of the disadvantages of this type of attachment is a reduction of first-stage stiffness. All four concepts, in particular shear ties, require extensive research and development work to establish their true relative merits.

Cluster Structure Development—Two variations of the chosen clustering concept were investigated. The final concept is described in detail in the succeeding section, Final Cluster Structure Design. The alternate concept consists of a stiffened cone mounted on the upper tank skirts. A ring was placed at the cone-skirt juncture of each motor case and served as the attachment point for the two interties between each motor case. The apexes of each of the cones were joined by a tubular member. Additional tubular members extended from the apex of each cone to the center of each motor case intertie. This formed a triangular truss extending from apex to intertie to adjacent apex back to original apex. The basic disadvantage of this concept was that it did not allow the upper-stage engines to fit into the forward motor-case skirts. A longer interstage section was therefore required.

The weight of this concept was approximately 15-percent greater than the weight of the chosen concept.

Final Cluster Structure Design—The selected clustering concept is shown in Figure IVA3-16 and -17. The basic principle is to provide fixity of the upper motor-case skirts while allowing differential expansion of the motor cases. No local attachments to the motor cases are required. On some vehicles, second-stage engines recess into the cluster structure to reduce interstage length. Upper-end fixity is achieved by attaching a barrel section to the upper skirt. The barrel section consists of two I-section rings of high-strength aluminum connected by a stressed skin panel, stiffened by Z-section stringers. The barrel sections are attached to each other by inner and outer crossties. The outer ties consist of a deep aluminum web, reinforced with Z-section stringers and terminating in an I-section beam which is bolted to the rings at each end of the barrel section. The inner ties consist of a welded-aluminum tubular-space truss bolted to the barrel-section rings.

The interstage shell consists of aluminum-stressed skin stiffened by Z-section stringers. The lower envelope of the shell is attached to the outer crossties and the outboard portion of the barrel sections. This results in a nonuniform stress distribution in the motor case walls as discussed earlier under Case Axial Loads.

The lower motor case skirts are connected by an intertie which allows relative displacement in the axial direction but provides restraint in the radial plane. The intertie is mounted on two internal aluminum rings which also provide the attachment point for the main fin spar. The intertie loads result from bending moments introduced into the upper tank ends by the nonuniform load distribution.

Riveted construction was used in the Z-section stringer panels and shell.

Cluster Structure Analysis—100,000-Pound Payload Vehicle—The cluster structure of one vehicle configuration was analyzed and its members sized for preliminary loads. Configuration 3-SC4 shown in Figure IVC1-1 was chosen for this study. The interstage structure analyzed included the external shell, the barrel interties, and the barrel rings.

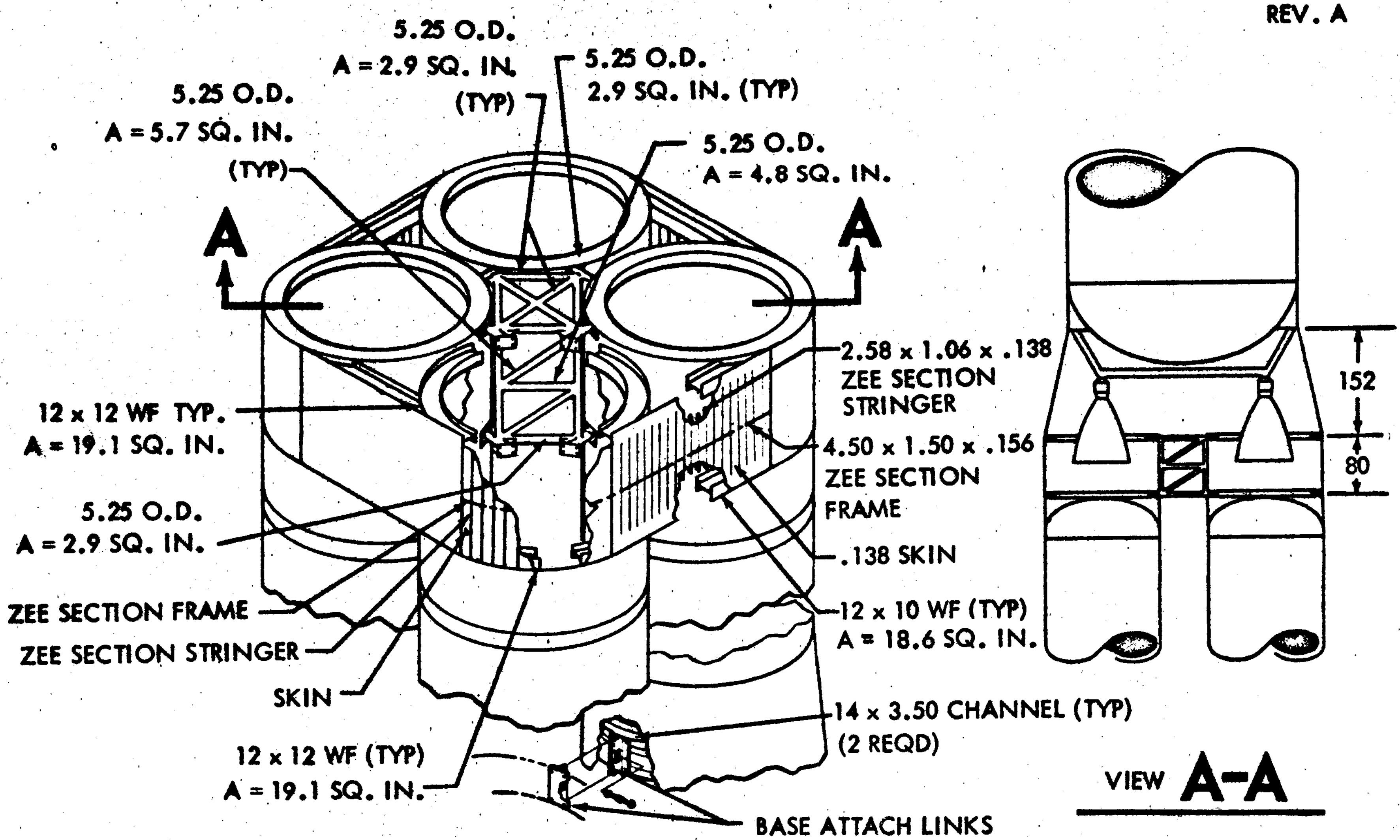


Fig. IV A3-16 BOOSTER MOTOR CLUSTERING CONCEPT

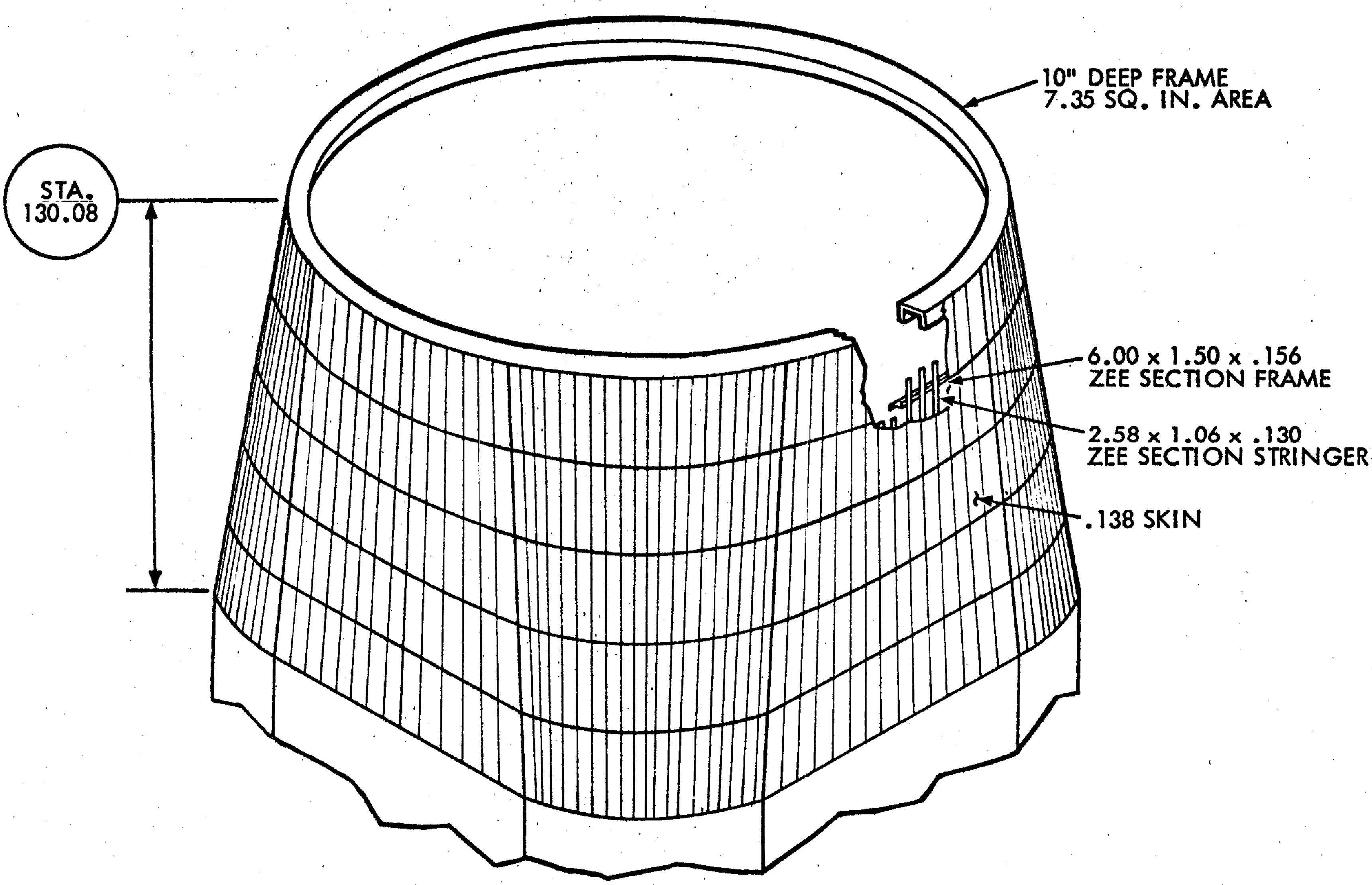


Fig. IV A3-17 INTERSTAGE STRUCTURE

The interstage structure is critical for two design-load conditions. Condition I occurs early in the boost trajectory where the aerodynamic forcing function is at maximum. Condition II occurs later in the trajectory at the time of first-stage burnout.

The interstage structure is built of aluminum with stress properties as defined under the heading of Material Selection.

The analyses and proposed structural sections for the interstage structure are shown in Figure IVA3-18 through -25. In these analyses, the axial load is conservatively assumed to be uniformly distributed in the tank skirts at the interstage base for the design of all the interstage structure. However, for the design of the tank skirts, the load was conservatively assumed to be nonuniform with a maximum value 50-percent greater than the uniform value of the load when distributed over 48 percent of the circumference.

1) Ground Rules:

Condition I (max. $(q/V)\, W_s \sin \gamma$) occurs at the point in the flight trajectory where the aerodynamic forcing function $(q/V)\, W_s \sin \gamma$ is a maximum. The preliminary ultimate loads used in the design of the interstage structure between stations 130.08 and 149.67 are as follows:

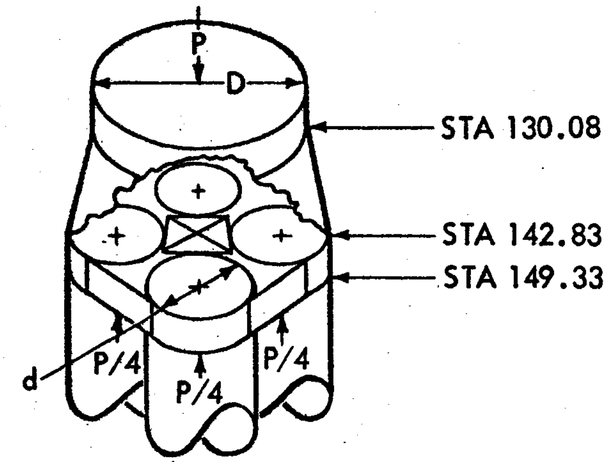
$M = 15.3 \times 10^6$ ft-lbs ultimate (at station 142.5)

$P_{axial} = (2.18 \times 10^6)(1.4) = 3.05 \times 10^6$ lbs ultimate.

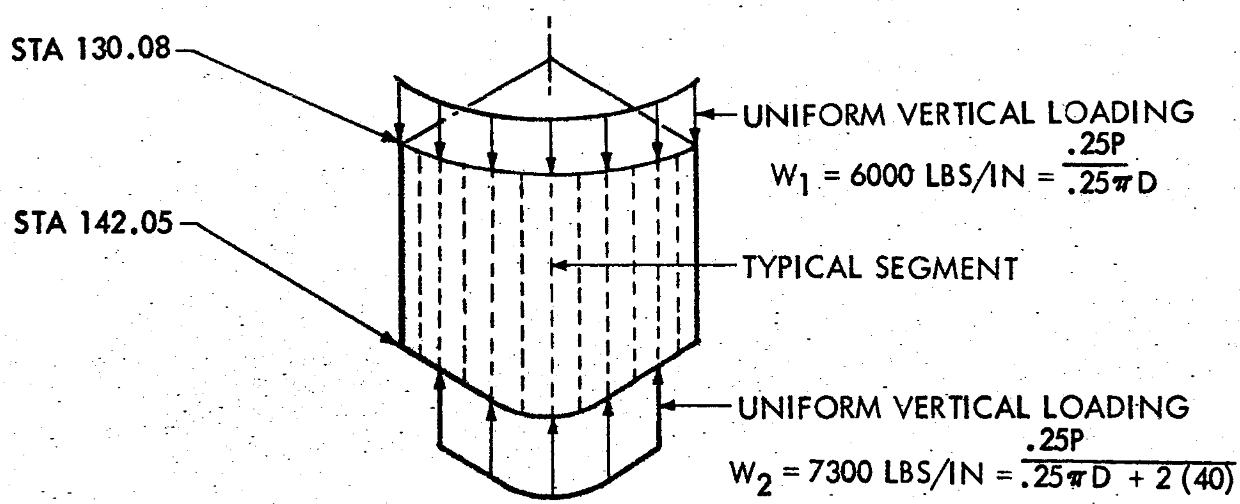
Condition II (Burnout) occurs at the time of first-stage burnout. The axial load is a maximum in the interstage structure at this time. The preliminary ultimate load for the design of the interstage structure between stations 130.08 and 149.67 is as follows:

$P_{axial} = (4.30 \times 10^6)$ lbs (1.4)

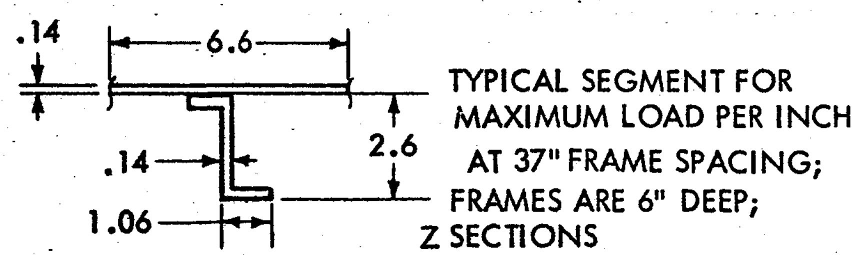
$= 6.02 \times 10^6$ lbs ultimate.



EQUILIBRIUM SKETCH (CONDITION II LOADING)



ASSUMED LOAD DISTRIBUTION IN A QUARTER SECTION



PROPOSED ALUMINUM SEGMENT

SHELL FROM STA 130.08 TO STA 142.5

Fig. IV A3-18 EXTERNAL SHELL ANALYSIS

GIVEN: TRIAL SECTION | TEST SECTION (14)

	TRIAL SECTION	TEST SECTION (14)
(1) $\bar{\sigma}$	$\cong$ 30,000 PSI TO 35,000 PSI	$\bar{\sigma}$ = 35,800 PSI
(2) P/b	= 7,530 LBS/IN	P/b = 3660 LBS/IN

FIND: PROPERTIES OF TRIAL SECTION
t_s, t, b, h, dF, dA and L

PROCEDURE:

(1) $$\frac{(P/b)\ TRIAL}{(P/b)\ TEST} = \frac{7530\ LBS/IN}{3660\ LBS/IN} = 2.05$$

(2) $$\frac{b\ TRIAL}{b\ TEST} = \frac{h\ TRIAL}{h\ TEST} = \frac{dF\ TRIAL}{dF\ TEST} = \frac{dA\ TRIAL}{dA\ TEST} = \frac{L\ TRIAL}{L\ TEST} = 2.05$$

PER REFERENCE SHOWN IN FIGURE IV 3A-20

(3) $$\frac{t_s\ TRIAL}{t_s\ TEST} = \frac{t\ TRIAL}{t\ TEST} = 2.05\ \frac{Fcy\ TEST}{Fcy\ TRIAL}$$

$$= 2.05\ \frac{66,000\ PSI}{62,000\ PSI} = 2.19$$

RESULTS:

	t_s	t	b	h	dF	dA	L	$\bar{\sigma}$
TEST SECTION (14)	.0635	.0624	3.21	1.26	.52	.44	20.35	35,800 PSI
TRIAL SECTION	.1391	.1367	6.58	2.58	1.06	.90	41.70	32,700 PSI

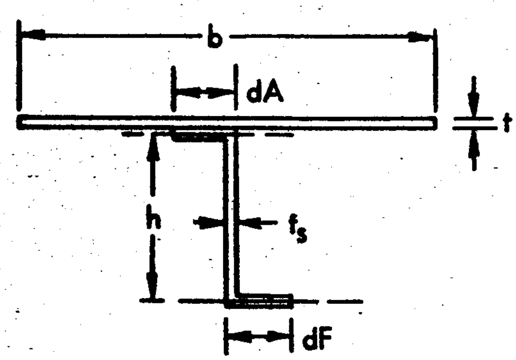


Fig. IV A3-19 EXTERNAL SHELL
(PROPOSED SKIN STIFFNER-SECTION)

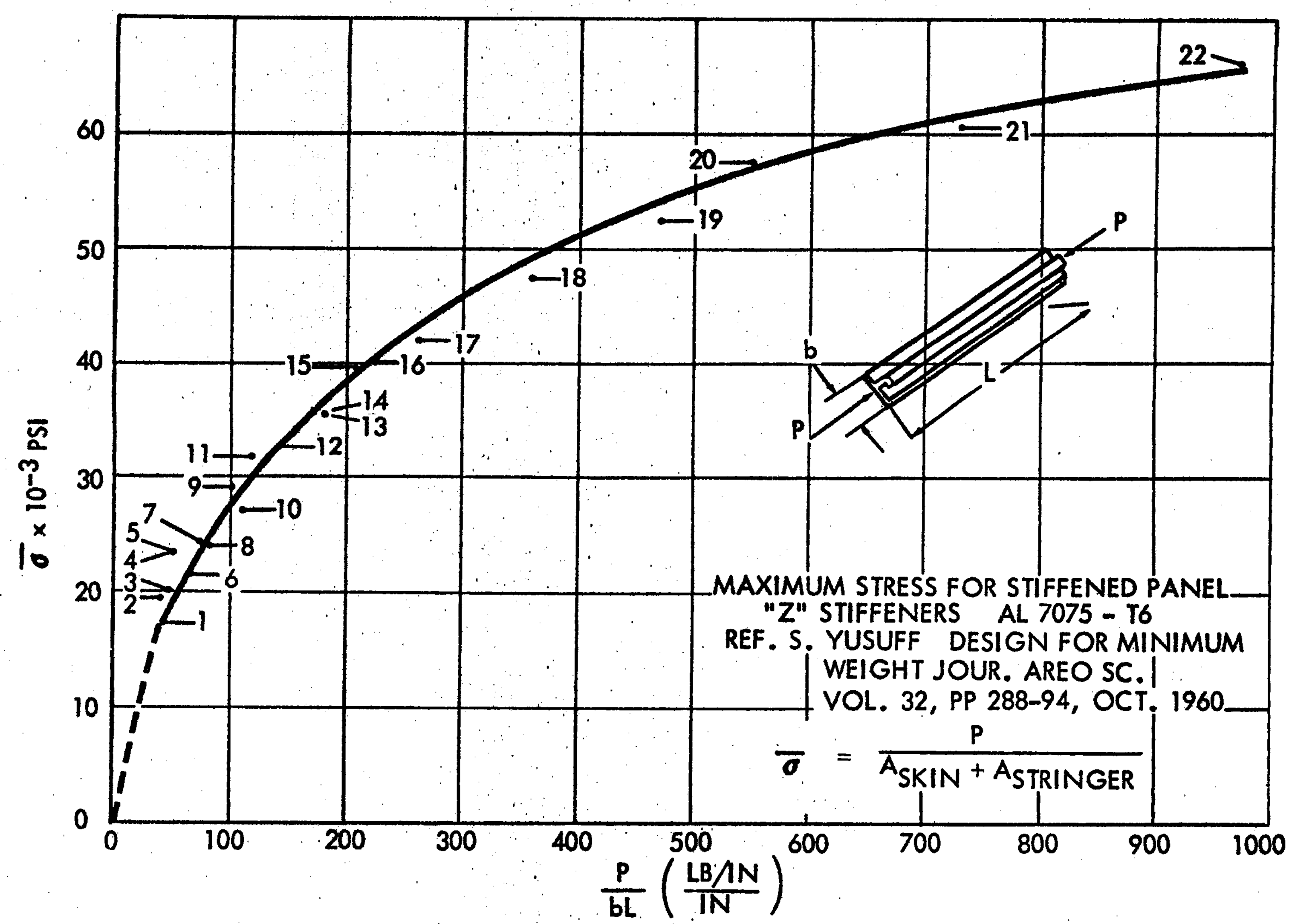
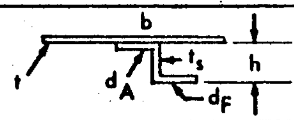


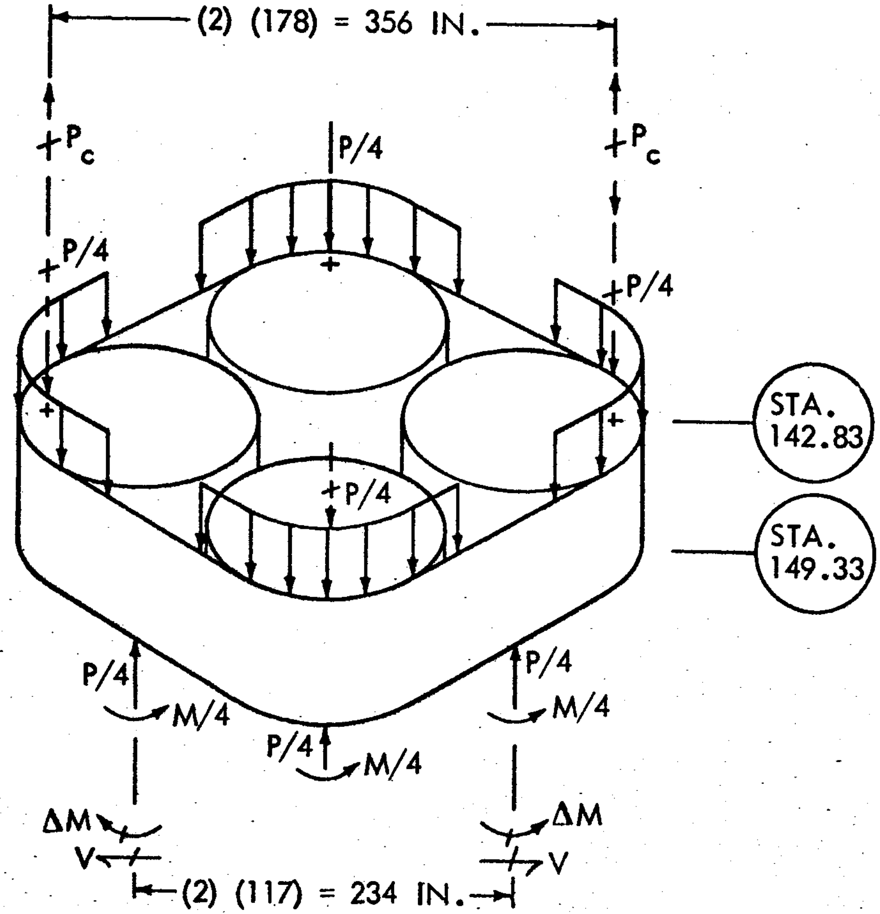
Fig. IV A3-20 AVERAGE STRESS VS. LOAD PER INCH



REF. S. YUSUFF DESIGN FOR MINIMUM WEIGHT. JOUR. AREO SC. VOL. 32, PP 288-94, OCT. 1960

	L(IN.)	t_s	t	b	h	d_F	d_A	$\bar{\sigma} \times 10^{-3}$	$\frac{P}{bL} \sim \frac{LB}{IN^2}$	$\frac{P}{b} \sim \frac{LB}{IN}$	$\bar{T}$
1	53.00	.0630	.1011	7.66	2.56	1.02	.69	17.4	40	2120	.1362
2	45.00	.0660	.0626	4.81	1.91	.77	.45	19.6	40	1800	.1055
3	57.00	.0638	.1018	5.11	2.56	1.02	.63	20.6	50	2850	.1544
4	30.10	.0625	.0621	3.17	1.27	.51	.43	23.2	50	1500	.1057
5	54.50	.0638	.0624	4.79	2.58	1.02	.42	23.3	50	2720	.1159
6	94.00	.1034	.1525	2.77	4.09	1.61	.99	21.7	60	5640	.4022
7	43.60	.1012	.1102	6.17	4.10	1.63	.69	24.2	70	3050	.2155
8	68.50	.1012	.1524	6.22	3.08	1.21	.98	23.9	80	5260	.2381
9	31.60	.0640	.0639	3.83	1.91	.77	.42	29.0	100	3160	.1157
10	65.30	.1043	.1561	6.38	4.07	1.61	.97	27.0	110	7180	.2648
11	32.30	.0654	.0626	3.20	1.93	.77	.42	31.9	120	3880	.1264
12	53.00	.1007	.1039	4.15	3.05	1.23	.69	32.7	140	7420	.2245
13	46.50	.1011	.1565	6.24	3.07	1.20	.99	35.9	180	8370	.2417
14	20.35	.0635	.0624	3.21	1.26	.52	.44	35.8	180	3660	.1063
15	49.10	.1004	.1535	4.82	3.07	1.20	.99	39.9	210	10,300	.2631
16	33.80	.0999	.1034	4.05	2.04	.79	.69	40.3	220	7440	.1902
17	34.90	.0993	.1034	3.06	2.04	.78	.67	42.0	260	9070	.2167
18	30.30	.1004	.1554	4.68	2.03	.81	.98	47.4	360	10,910	.235
19	20.00	.0982	.1032	3.06	1.24	.48	.68	52.5	470	9400	.1802
20	22.75	.1016	.1047	3.07	2.06	.80	.67	57.7	550	12,510	.2215
21	20.50	.0998	.1545	3.89	2.04	.81	.98	60.6	730	14,960	.2528
22	13.15	.0998	.1024	2.56	1.23	.48	.68	66.3	970	12,760	.1956

Fig. IV A3-21 PROPORTIONS OF "Z" STIFFENER PANELS



DESIGN LOADS — CONDITION I (MAX $(q/V)W_s \sin\gamma$)

$M = 183.6 \times 10^6$ IN. LBS. ULT. $M/4 = 45.9 \times 10^6$ IN. LB ULTIMATE

$P = 3.05 \times 10^6$ LBS. ULTIMATE $P/4 = 762{,}500$ LB ULTIMATE

$$P_c = \frac{M \text{ IN. LB.}}{356 \text{ IN.}} = 515{,}700 \text{ LBS. ULTIMATE}$$

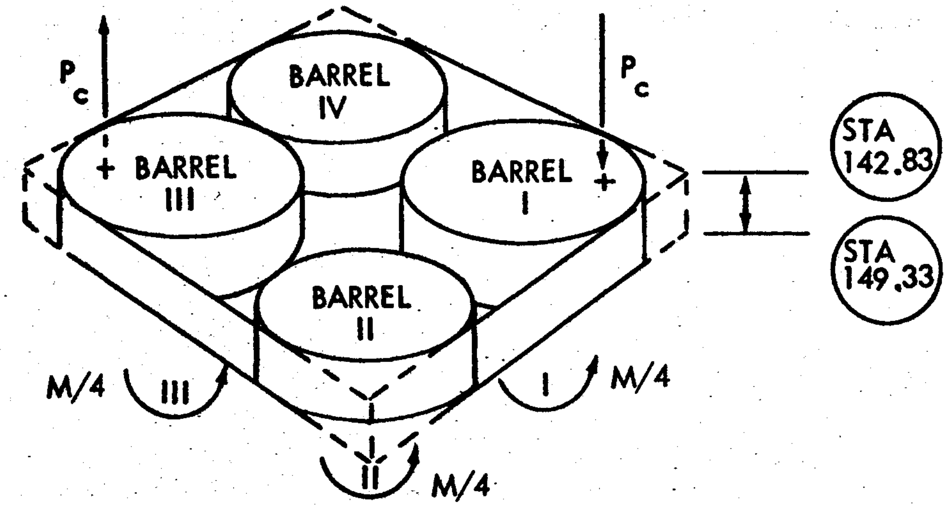
$$\Delta M = (K)\,(P/4)\,(178-117) = 39.5 \times 10^6 \text{ IN. LBS}$$

K = .85 : COEFFICIENT DEFINING THE ESTIMATED PROPORTION OF ΔM REACTED AS A COUPLE LOAD AT STATIONS 146.08 AND 186.67

$$V = \frac{\Delta M}{(186.67 - 146.08)\,(12 \text{ IN/FT})} = 81{,}100 \text{ LBS.}$$

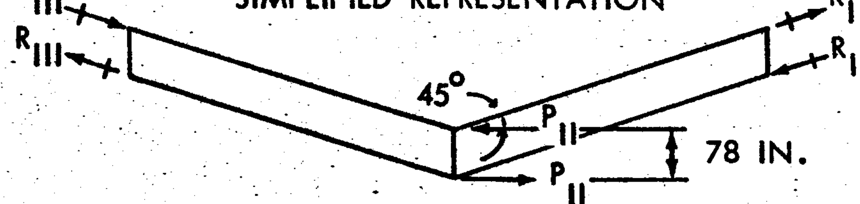
Fig. IV A3-22 DESIGN LOADS FOR BARRELS AND BARREL INTERTIES BETWEEN STATIONS 142.83 TO 149.33

OUTSIDE MEMBERS — CONFIGURATION



DESIGN LOADS FROM CONDITION I

SIMPLIFIED REPRESENTATION



THE OUTSIDE INTERTIES ARE ASSUMED TO TRANSFER ALL MOMENT IN BARRELS II AND IV TO THE REACTION POINTS ON BARRELS I AND III.

$R_I = (.707)\ P_{II} \quad \therefore \quad R_I = 416{,}000$ LBS

$P_{II} = (M/4)\frac{1}{78 \text{ INS.}} \quad \therefore \quad P_{II} = 588{,}500$ LBS.

$(M/4) = 45.9 \times 10^6$ IN-LBS

PROPOSED STRUCTURAL CHORD MEMBERS

ALUMINUM
SECTION

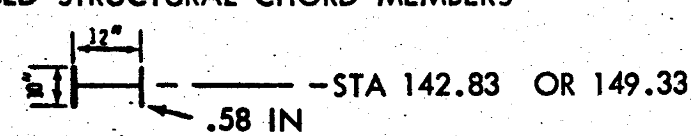
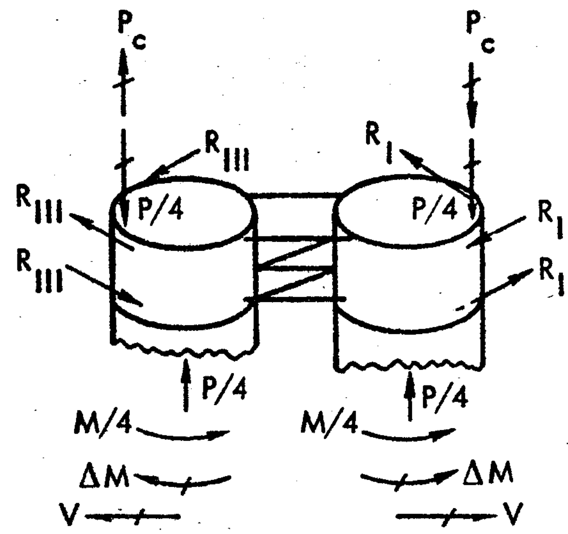
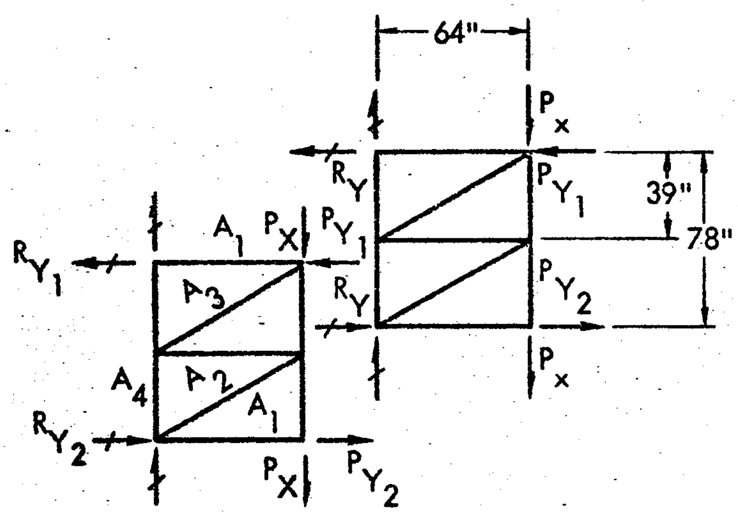


Fig. IV A3-23 BARREL INTERTIE STRUCTURE



INSIDE MEMBERS — CONFIGURATION



$P_x = \frac{P_c}{4} + 36,300$ LBS

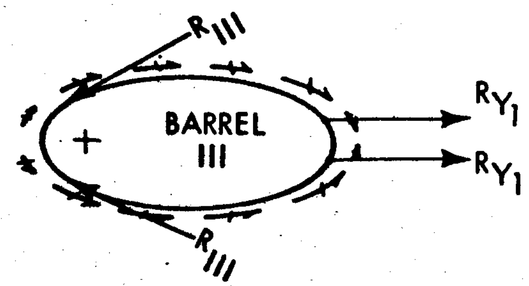
$P_x = 165,200$ LBS.

	LBS.	O.D., IN.	SQ. IN.	
$P_{c/4}$	= 128,900	D_1 = 5.25	A_1 = 2.9	ALUMINUM TUBING
P_{Y_1}	= 111,100	D_2 = 5.25	A_2 = 4.8	
P_{Y_2}	= 70,500	D_3 = 5.25	A_3 = 5.7	
		D_4 = 5.25	A_4 = 2.9	
R_{Y_1}	= 160,000			
R_{Y_2}	= 200,600			

INSIDE MEMBER LOADS — CONDITION I

Fig. IV A3-24 BARREL INTERTIE STRUCTURE

BARREL RINGS — STATIONS 142.83 AND 149.33

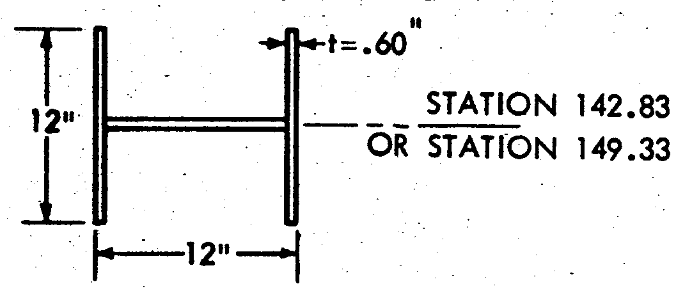


DESIGN LOADS — CONDITION I

R_{III} = 416,000 LBS.

R_{Y_1} = 200,600 LBS.

PROPOSED STRUCTURAL CROSS SECTION



MATERIAL : ALUMINUM
AREA = 19.1 SQ. INS.

Fig. IV A3-25 BARREL STRUCTURE

Material allowables are defined in the section on Material Selection.

Design load factors are defined in the section on Design Criteria.

2) Analysis and Results:

The critical design load for the external shell (between Sta's. 130.08 and 142.5). occurs in condition II (burnout). The estimated distribution of load is shown in Figure IVA3-18 along with a proposed skin-stiffener section and compatible frame spacing. The frame size is also indicated. Figures IVA3-19, -20, and -21 summarize the method used to size the skin-stiffener section.

The total load distribution on the barrels and barrel interties is shown in Figure IVA3-22. The specific loads carried by the outer members are shown in Figure IVA3-23. The estimated size of these members is also shown in this figure.

The load distribution on the innertie truss (inner) members is shown in Figure IVA3-24. The size of the truss members is also defined in this figure.

The loads on the barrel rings are shown in Figure IVA3-25 along with the estimated size of the structural ring required. The skin and stiffener sections in the barrel were not sized in this analysis. It is estimated that they would be somewhat larger than the external shell sections of Figure IVA3-18.

Ignition Effects—Since the vehicle is skirt-supported at launch, variations in ignition time of motors must be investigated. The estimated variations in ignition time and the corresponding pressure traces are shown in Figure IVA3-26. Two sigma variations in pressure traces result in a possible variation of 500 psi between motor cases. Figure IVA3-27 shows the longitudinal tank growth of the various configurations at a pressure of 500 psi and at limit pressure. At 500 psi the tank growth varies from .15 inches in the 100,000-pound-payload vehicle to .4 inches in the 180,000-pound-payload vehicle. This relative growth occurs for

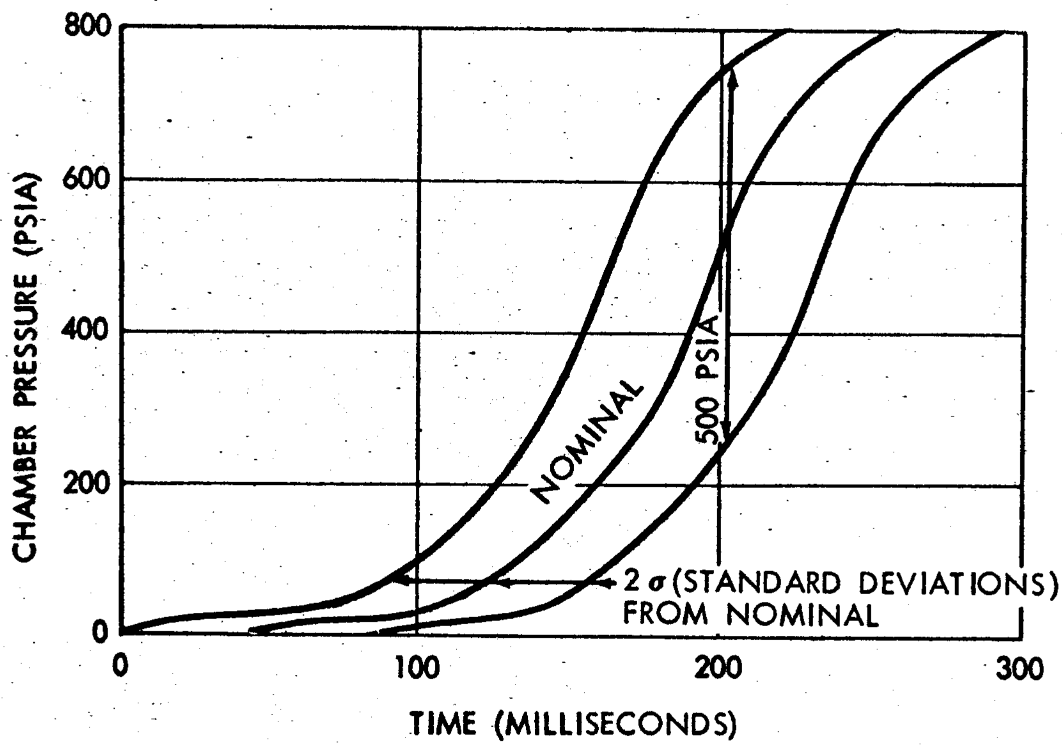


Fig. IV A3-26 IGNITION VARIATIONS OF SOLID MOTORS

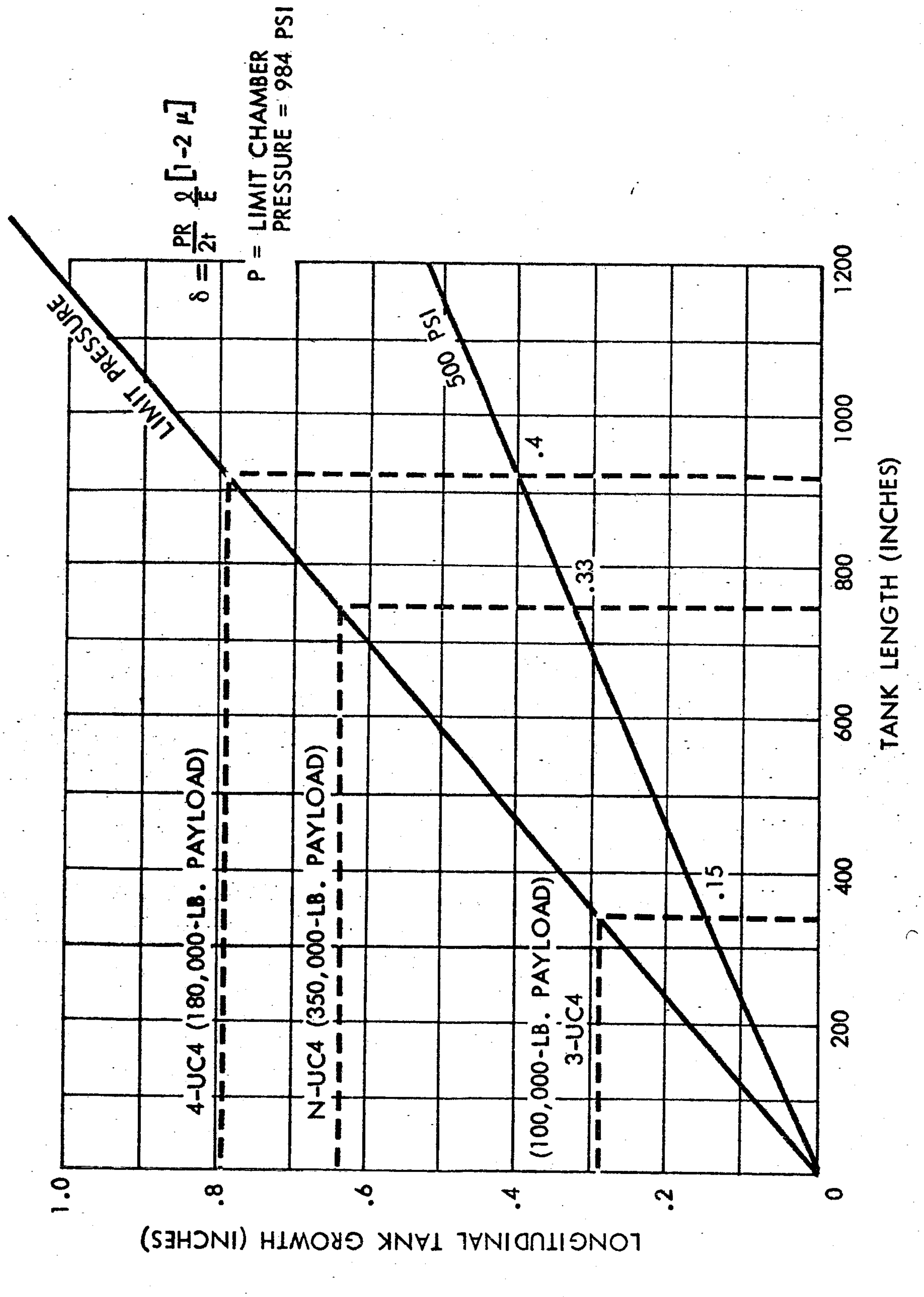


Fig. IV A3-27 LONGITUDINAL TANK GROWTH VS. TANK LENGTH a period of approximately 125 milliseconds. A static analysis showed that these deflections could be absorbed in the intertie structure. However, further dynamic analysis will be required in this area.

The ignition shock in the interstage shell region was estimated from a previous dynamic analysis of a cluster of four first-stage solid motors with a total thrust of 900,000 pounds. All engines were assumed to ignite simultaneously to produce maximum axial shock. The resulting interstage load was 14-percent greater than the applied thrust load. This condition also produced approximately a three-g load on the motor case skirts.

Based on Minuteman project experience, dynamic analysis predictions were found to be conservative when compared with test results. The 14-percent thrust increase at the interstage is therefore estimated to be a conservative value.

Panel Flutter

The panel flutter criteria used in this study is shown in Figure IVA3-28. The critical flutter condition occurred in the transonic region. The interstage shell shown in Figure IVA3-17 was adequate with a margin of safety of 1.23.

Fins

The vehicle fins were attached to the lower skirt. The main fin spar is anchored by two rings, one above and one below. The spar protrudes between the rings; and a compression member, attached perpendicular to the spar end, anchors the spar to the rings.

Fin loads were obtained from Reference H for subsonic flow. Reference I describes the method used to determine the supersonic values including interference of the body on the fin.

Thrust Vector Control Tankage

TVC tanks were designed for internal pressures up to 5000 psia. A safety factor of 2.5 was used to insure personnel safety. Tank diameters up to 80 inches were

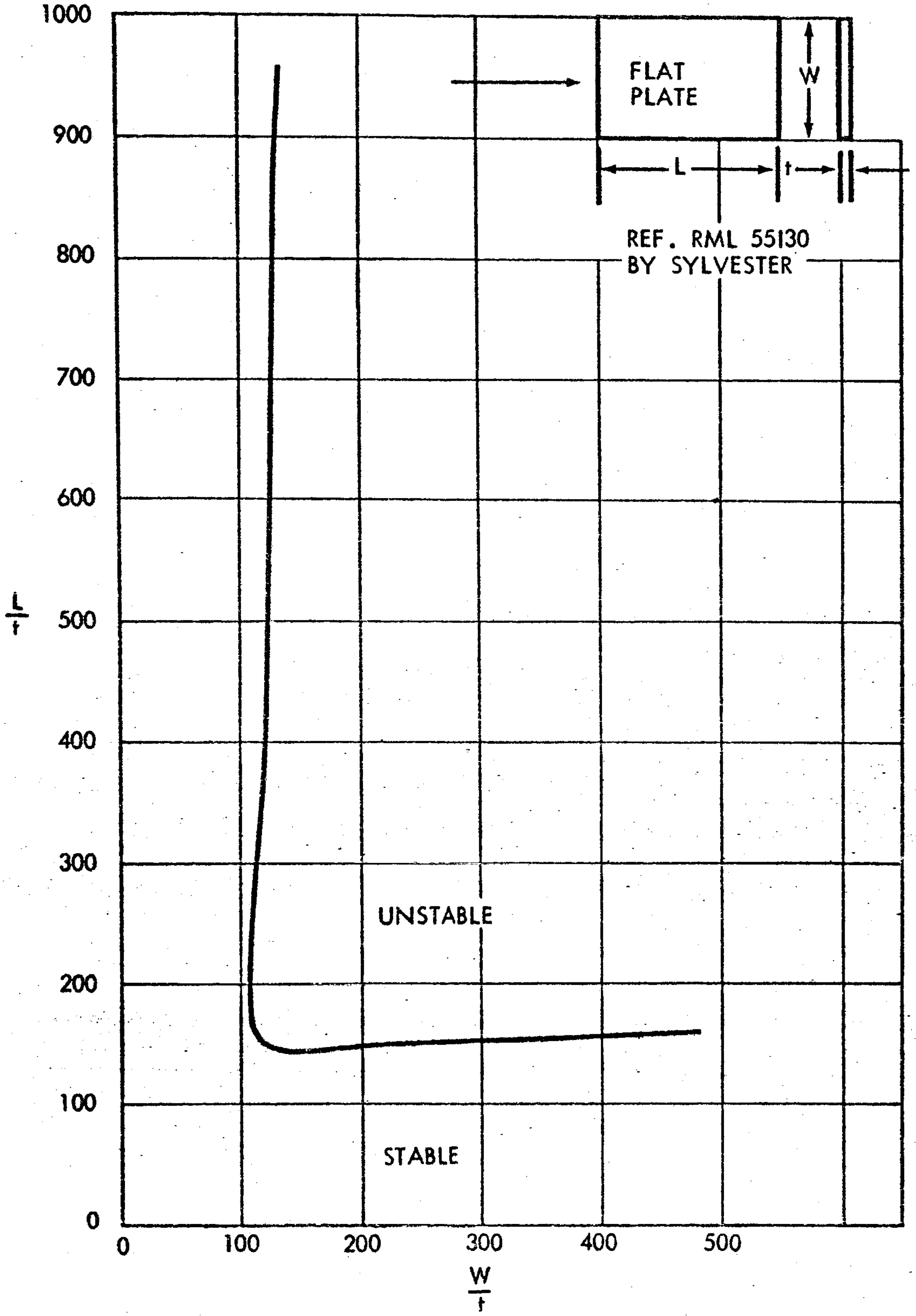


Fig. IV A3-28 PANEL FLUTTER AT CRITICAL CONDITION IN TRANSONIC REGION (MAX. $\frac{1}{\sqrt{\beta_1}}$ 9) used. The resulting thicknesses would mean operating in the brittle fracture range for steels. Therefore, annealed titanium with an ultimate stress of 120,000 psi was used. The maximum TVC tank thickness (350,000-pound-payload helium tank) was 2.31 inches.

Second Stage

Ground Rules

The second stage design was pursued only to the detail necessary to predict representative weights. Basic ground rules, consistent with current best information, are:

1) Aluminum waffle pattern construction
2) Internal Pressures

   LO_2 = 32 psia LH_2 = 27 psia
3) Common Bulkhead—Honeycomb with fiberglass core

LH_2 and LO_2 Tanks

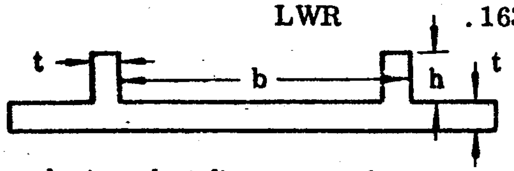
The LH_2 tanks were designed of aluminum waffle-pattern-stiffened panels. Panel sections would be milled from sheet stock with land areas at all welded joints. The panels terminate in monocoque sections at the tank head juncture which will be a Y-section ring.

LO_2 tank walls in the 30,000-pound payload vehicle are similar to those in the LH_2 tank construction. In the other configurations, the LO_2 tank wall was shortened to the point where stiffened-panel load-redistribution effects were of prime importance. In these cases, a simple monocoque cylinder was used. Table IVA3-9 presents the waffle pattern sizing for the study vehicles.

Table IVA3-9

WAFFLE PATTERN SIZING

Configuration	Tank	Location	t	b	h
30,000-Lb. Payload	LH_2	UPR End	.0507	6.29	.205
		LWR	.0529	6.29	.395
	LO_2	UPR	.0658	7.9	.377
		LWR	.106	7.9	.33
100,000- and 180,000-Lb. Payload	LH_2	UPR	.102	16.24	.488
		LWR	.106	16.24	.62
350,000-Lb. Payload	LWR	UPR	.1258	22.85	.641
		LWR	.163	22.85	.841



Tank gages (t) were designed at first-stage burnout. Cryogenic allowables were used. Upper-stage ground wind and flight loads are summarized in Loads Analysis.

Common Bulkhead Design

The common bulkhead between the LO_2 and LH_2 tanks consists of a honeycomb shell with aluminum faces and a fiberglass core which provides both insulating capacity and strength.

The common bulkhead was designed for the maximum of two loading conditions. The maximum tension load resulted from the LO_2 tank filled and pressurized, with atmospheric pressure in the LH_2 tank. The maximum compressive load was due to loss of pressure in the LO_2 tank with the vehicle in the flight-ready condition.

Table AIV3-10 summarizes the bulkhead size requirements for the study vehicles.

Table IVA3-10

HONEYCOMB BULKHEAD REQUIREMENTS

	Thickness of Faces (in.)	Overall Thickness (in.)	Core Density (Lb/Ft^3)
30,000-Lb. Payload	.01	.5	5
100,000- and 180,000-Lb. Payload	.0189	1.88	4.5
350,000-Lb. Payload	.033	2.32	3.0

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A. "Dynamic Investigations of Thrust Buildup and Cutoff for the Saturn Vehicle," Glaser, R. F., and Christien, D.C., MTP-M-S&M-62-5, June 12, 1961

B. "The Apollo 'A'/Saturn C-1 Launch Vehicle System," George C. Marshall Space Flight Center document No., MPR-M-SAT-61-5, July 17, 1961

C. WADC TR 59-504

D. Volume I of this series (D2-20500-1)

E. "General Environmental Criteria for Guided Missile Weapon Systems," U.S. Air Force Specification Bulletin 106-A

F. "Power Spectral Density Technique in Ground Wind Drag Analysis," Boeing document D2-11737

G. Marks, L.S., Mechanical Engineers Handbook.

H. NACA TN 3911

I. NACA Report 1307

4. FLIGHT CONTROL

Flight-control studies provided preliminary analyses of configuration stability-and-control and flight-control requirements. The objective was to obtain a broad survey of stability and control characteristics of six selected vehicles to indicate the problem areas and possible methods of solution. The following were the major conclusions.

1) Solid boosters tend to be more unstable than liquid boosters due to the higher trajectory dynamic pressure at which they optimize. In addition, the use of a solid first stage, while retaining liquid upper stages and first-stage clustering, aggravates the problem, and fins are required to meet a minimum crew-escape-time criterion. In comparison, vehicles of this size with either all-liquid or all-solid stages would probably not require fins for this criterion.
2) Control requirements during boost are generally low for vehicles of this size due to high moments of inertia; thrust deflections of less than 2 degrees are required for the most severe wind conditions. Stage separation, however, requires careful consideration because of the long thrust decay of the solid motor which requires low vehicle uncontrolled-divergence rates or auxiliary control. Clustering aggravates the stage-separation problem and requires appreciable nozzle cant angles.
3) Coupling between the control system and the flexible structure appears to be more of a problem for the solid booster due to the effect of its high density on the vehicle's mass distribution and the requirement for clustering on the larger vehicles. Ratios of first-mode body-bending frequency to pitch-control frequency of five were obtained, but larger values would be desirable. This suggests lower vehicle fineness ratios, increased stiffness, or lower pitch control frequencies.
4) Fluid injection was chosen for the thrust-vector-control system as representative of the methods currently considered feasible for long-burning solid motors. No attempt was made to determine the optimum system. However, a brief survey of control methods for long-burning solid motors indicates

that the main systems under consideration are nozzle fluid injection and auxiliary solid-rocket motors. Both methods require relatively large control-system propellant weights and a high degree of system complexity.

Gimbaled nozzles are considerably more efficient and reliable, but require further study and development due to the materials and sealing problem for the long burning time.

It is recommended that further emphasis be placed on the development of solid-motor gimbaled-nozzle state of the art and that a detailed comparison of the three methods be made.

FLIGHT-CONTROL DESIGN CRITERIA

The booster flight-control design criteria were based on present large-booster design practice modified where necessary for the manned-mission objectives. The following paragraphs describe the ground rules and methods used.

Vehicle Aerodynamic Stability

Large boosters are normally unstable aerodynamically and derive their stability and control from an automatic stabilization system. However, the degree to which they are unstable has a strong influence on vehicle motions in event of autopilot failure or during the staging process when control is marginal or nonexistent. The stability criteria used in this study were based upon crew-escape considerations with the autopilot failed. Since the important parameter is sufficient time for crew decision, a criterion of vehicle uncontrolled divergence rate is used rather than stability margin. The ground rule used is that the time-to-double-amplitude for the uncontrolled-vehicle angle-of-attack motion is never less than 2 seconds. This is illustrated in Figure IVA4-1. The trajectory maximum dynamic pressure point is the most critical point for this analysis. For vehicles so unstable that the time-to-double-amplitude is less than 2 seconds, fins are added to increase the time to this value.

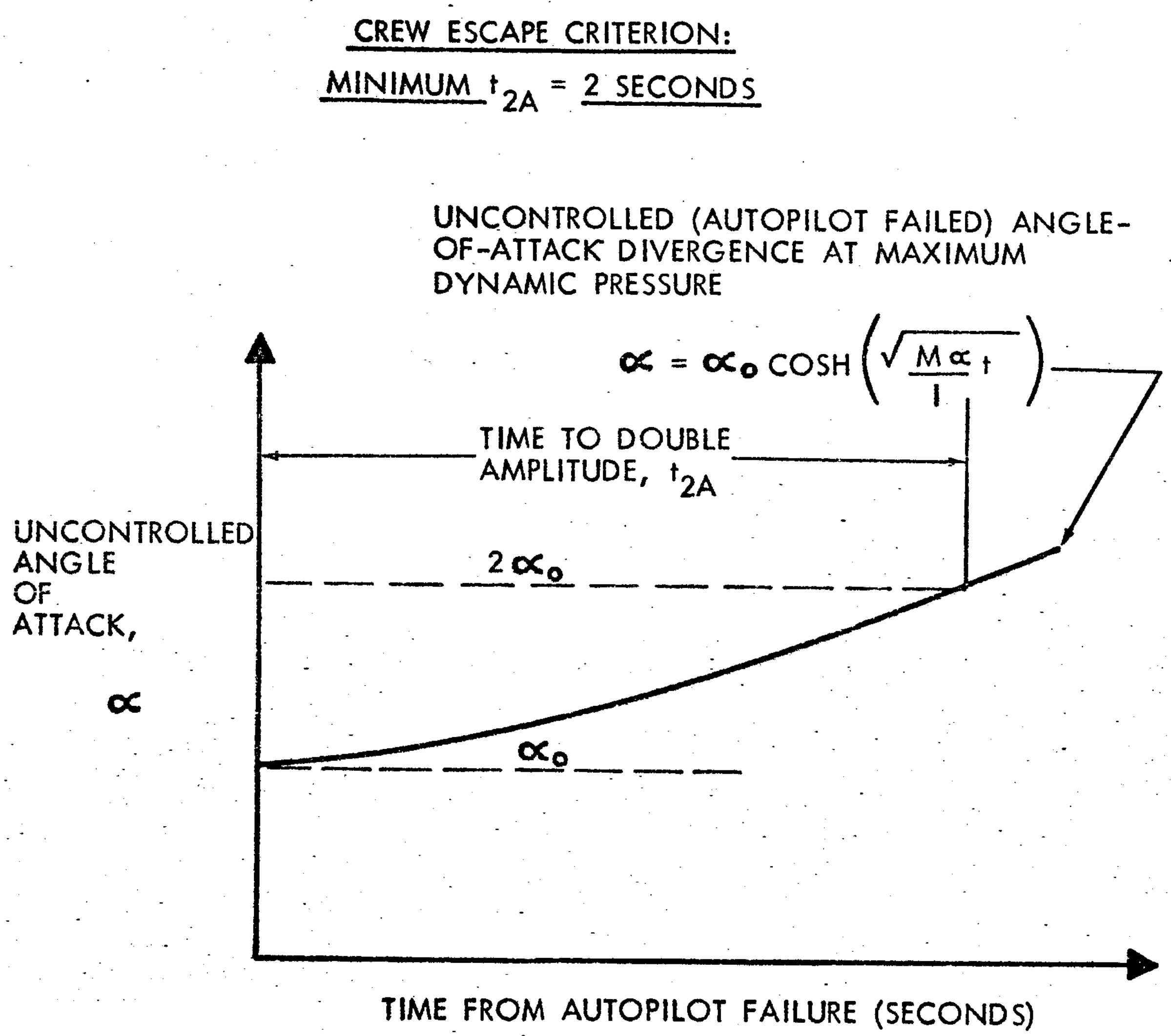


Fig. IV A4-1 BOOSTER CREW-ESCAPE STABILITY CRITERION

Boost-Control Requirements

The booster autopilot and thrust-vector-control system must maintain vehicle stability and control about three axes during boost in the presence of winds, misalignments, and variations in motor performance. The critical phases of boost in meeting these requirements are at maximum dynamic pressure where aerodynamic instability is greatest and at burnout where control forces are most marginal.

During the study, these critical phases of boost flight were examined for each vehicle. No detailed dynamic analyses were made; the flight characteristics and control requirements were based on simplified methods and past experience that allow a broad coverage of all configurations considered.

Vehicle Maximum Thrust-Vector Angle

The largest control-deflection requirement comes from flying through the design wind. The design wind consists of a relatively slowly increasing wind speed at low altitudes and a sharp spike at maximum dynamic pressure. A typical boost-time history for a vehicle with a minimum time-to-double amplitude of 2 seconds is shown in Figure IVA4-2. The maximum thrust-vector angle is found to be closely approximated by that required for a steady-state trim of an angle of attack of 6 degrees. This approximation was used for determining the maximum thrust-vector angle at maximum dynamic pressure. To this must be added the effects of thrust-vector misalignment, center-of-gravity offset, and thrust variations. A neutral-burning (constant thrust with time) motor was assumed for these calculations. Typical thrust-vectoring requirements for these effects were:

1)	Thrust-vector misalignment	0.25°
2)	Center-of-gravity offset (1 inch from centerline)	0.10°
3)	Thrust variation (+4.5% on one side and -4.5% on the other)	0.12°
4)	Fin misalignment (±0.5°)	0.03°
	Maximum total misalignment thrust-vector angle requirement	0.50°

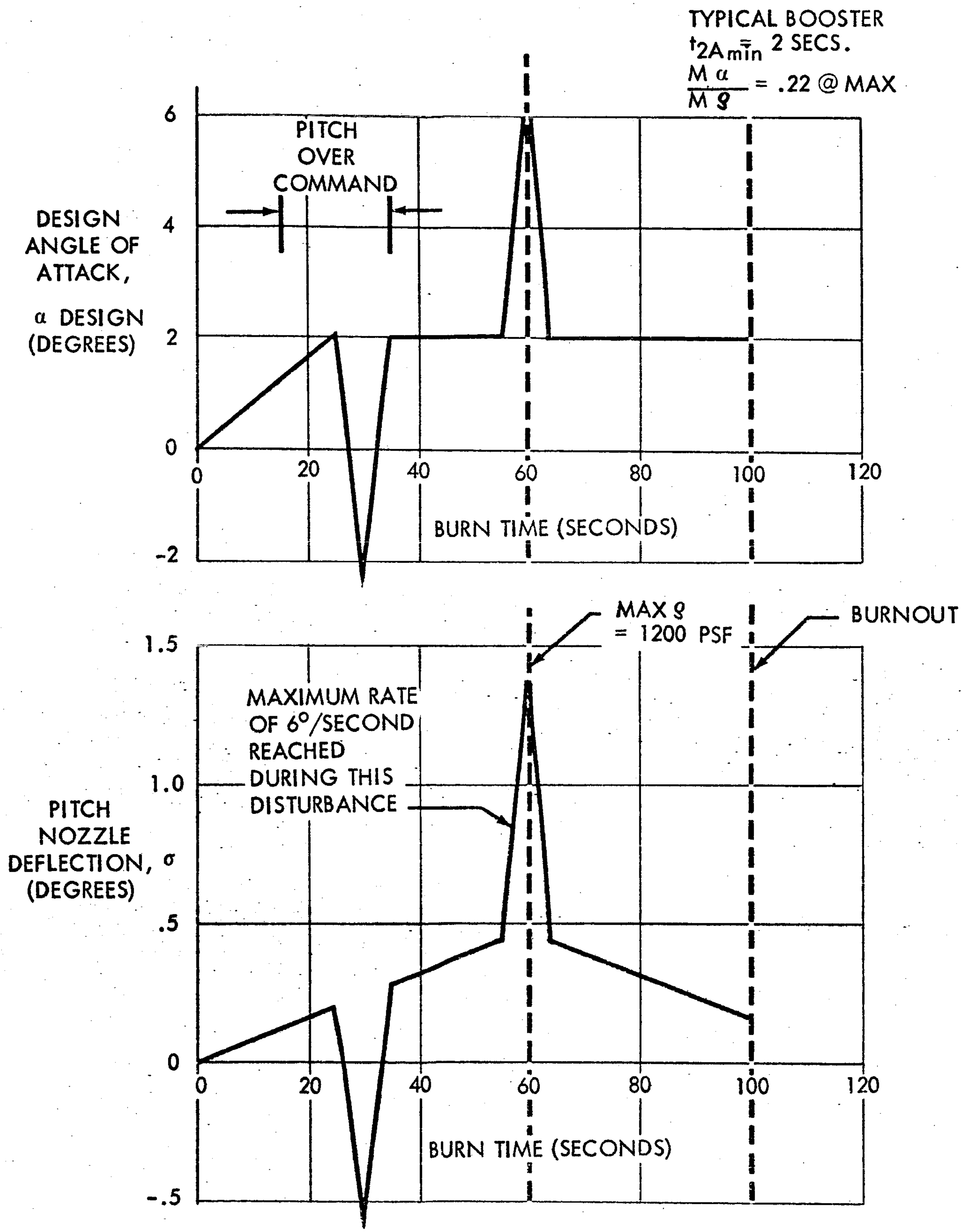


Fig. IV A4-2 TYPICAL CONTROL-TIME HISTORY THROUGH WIND

The above total must be added to the values computed from the wind considerations to obtain the total angle required. In all cases, it is assumed that total stage thrust is deflected.

Nozzle Cant Angle

For clustered boosters, the nozzles are canted to aim the thrust through the center of gravity at burnout. This is required to minimize angular impulses during the thrust tailoff at burnout.

Control Impulse

The required control-system impulse was estimated from a combination of the misalignment errors and wind disturbances discussed above. The average values of the misalignment errors during the mission are somewhat less than the maximum values tabulated above due to center-of-gravity travel, nozzle cant angle (in the case of the thrust variation), and dynamic-pressure variation (in the case of fin misalignment). The required control-system impulse is computed from the following relation:

$$\% \text{ Control Impulse} = \frac{\text{(Thrust Deflection, deg.) (Total Thrust) (Time)}}{57.3 \text{ (Total Thrust) (Time)}} \times 100$$

$$= \frac{\text{(Thrust Deflection, deg.) (100)}}{57.3}$$

The values of control impulse for thrust-vector misalignment and center-of-gravity offset were multiplied by a factor of $\sqrt{2}$ for the most severe pitch-and-yaw case. The values of impulse for the thrust-variation and fin-misalignment errors are doubled to account for pitch and yaw.

The nozzle-vectoring requirements due to wind (shown in Figure IVA4-2) were adjusted by the $\frac{M\alpha}{M\delta}$ ratio for each individual vehicle in determining total system impulse, where $\frac{M\alpha}{M\delta}$ is the ratio of aerodynamic moment per angle of attack to the control moment per deflection. In a similar fashion to the thrust-vector-misalignment and center-of-gravity offset errors, the wind-impulse requirements were multiplied by a factor of $\sqrt{2}$ for the most severe pitch-and-yaw case. The required control impulse for a typical vehicle is summarized below.

REQUIRED CONTROL IMPULSE

Average misalignment error impulse			
1) Thrust-vector misalignment	($\sqrt{2}$) (0.437)	=	0.61
2) Center-of-gravity offset	($\sqrt{2}$) (0.140)	=	0.20
3) Thrust variations	(2) (0.105)	=	0.21
4) Fin misalignment	(2) (0.035)	=	0.07
Wind disturbance	($\sqrt{2}$) (0.467)	=	0.65
Total control impulse, percent total impulse		=	1.74

Figure IVA4-3 presents the results of these calculations as a function of vehicle launch weight. As vehicle size increases, the percent of first-stage impulse required for control tends to decrease but is somewhat obscured by individual configuration differences.

Stage Separation

The solid boosters tend to have higher burnout dynamic pressures (due to their optimization of higher thrust-to-weight ratio and short burn time) and also have the characteristic of a long thrust tailoff at burnout. Both conditions pose control problems at stage separation that are more severe than for liquid boosters. The second stages are liquid-hydrogen fueled and require a chill-down period before start (with an attendant explosion hazard from unburned fuel). Consequently, a fire-in-the-hole type of stage separation is not considered feasible for these vehicles. During the thrust tailoff, when there is still enough thrust to make separation unfeasible (because of the large retrorocket thrust required), there is a short time of reduced control. This region and the coast region after separation may restrict the burnout dynamic pressure or require additional control capability. Thrust termination is also a possible method of reducing the

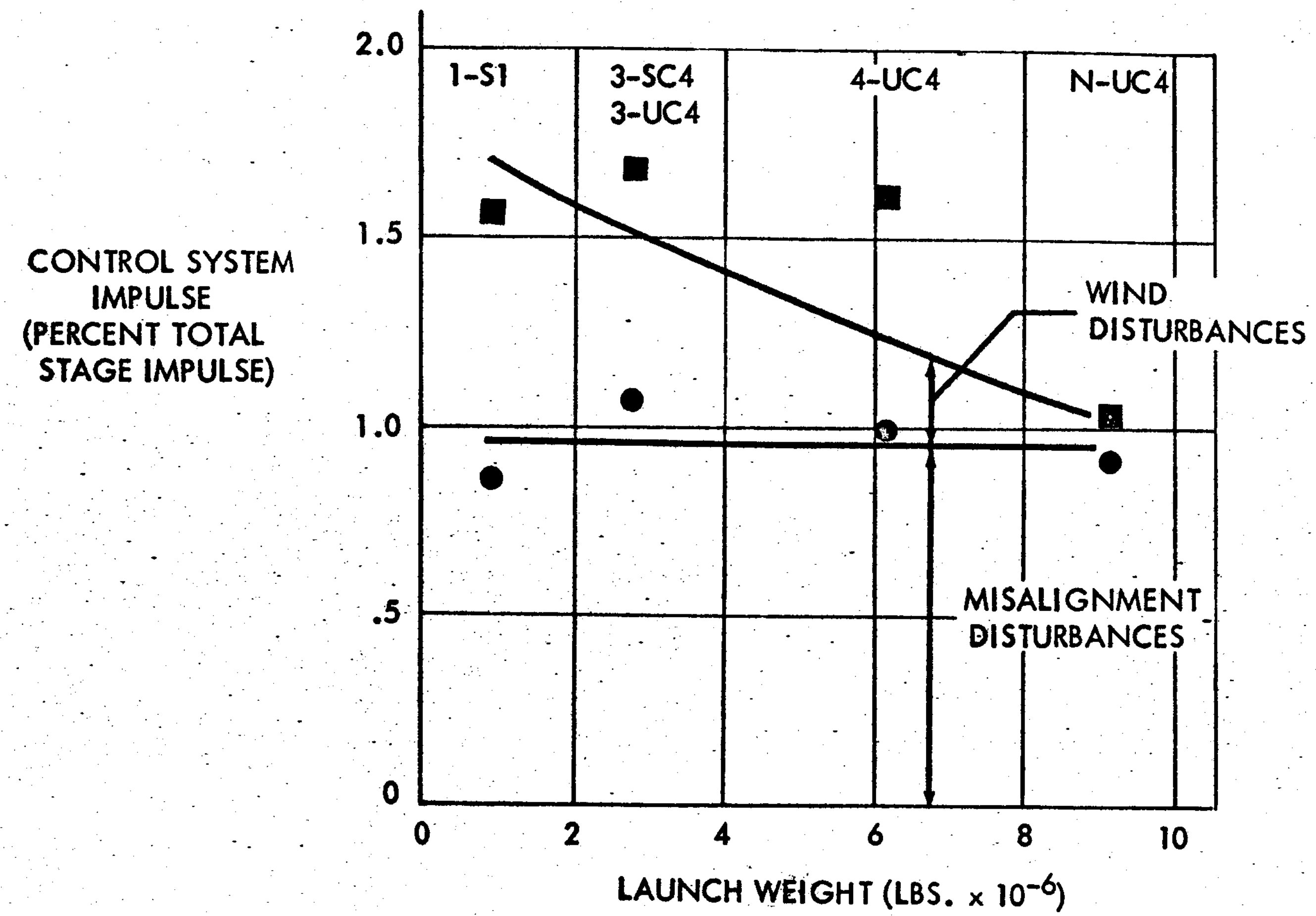


Fig. IV A4-3 CONTROL SYSTEM IMPULSE REQUIREMENTS period of marginal control but is not favored because of its weight and complexity. Preliminary studies indicate that, for large boosters such as considered in this study, uncontrolled motions will remain within tolerable limits for dynamic pressures below 200 psf. The fluid-injection thrust-vector-control system requires additional study to establish the magnitude of control forces during the thrust tailoff.

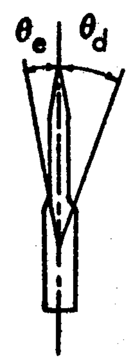
Pitch-Control Frequency

The booster pitch-control frequency must be high enough to provide proper response to wind disturbances and flight-path control commands, but must be low enough to avoid undesirable couplings between the control system and the flexible structure vibrations which are fed into the control system through the control sensors. The lowest possible pitch-control frequency is chosen to provide the maximum spread from the first-mode body-bending frequency. The criteria for the lower limit of this pitch frequency were based on the steady-state error of the closed-loop control response. For a given aerodynamic stability (in this case, that which results in a time-to-double-amplitude of 2 seconds), the ratio of closed-loop steady-state error to a disturbance or command increases as the pitch control frequency is reduced. This is shown in Figure IVA4-4. A maximum value for the steady-state error ratio equal to 0.5 was used to determine the minimum pitch-control frequency. This results in a minimum pitch-control frequency of 0.15 cps.

CONFIGURATION TRADE STUDIES

Effect of Clustering

The effect of clustering on vehicle stability and control was studied for the 30,000-pound-payload vehicle. The number of first-stage motors was varied from one to four and the stability analyzed at maximum dynamic pressure. Figure IVA4-5 shows the effect of number of first-stage motors on time-to-double-amplitude and fin size required to meet a 2-second time-to-double-amplitude.



$$\frac{\theta_e}{\theta_d} = \frac{\text{CLOSED LOOP STEADY-STATE ERROR}}{\text{DISTURBANCE MAGNITUDE}}$$

$$= \frac{1}{\left(\frac{M_\delta / I}{M_\alpha / I}\right) K_\theta - 1}$$ WHERE

M_α = AERODYNAMIC MOMENT PER ANGLE OF ATTACK

M_δ = CONTROL MOMENT PER DEFLECTION

I = INERTIA

ALSO $$K_\theta = \frac{\omega^2 + M_\alpha / I}{M_\delta / I}$$

FOR ATTITUDE CONTROL SYSTEM WHERE ω = PITCH CONTROL FREQUENCY

$$\therefore \frac{\theta_e}{\theta_d} = \frac{1}{\left(\frac{M_\delta / I}{M_\alpha / I}\right)\left(\frac{\omega^2 + M_\alpha / I}{M_\delta / I}\right) - 1} = \frac{1}{\omega^2}\left(\frac{M_\alpha}{I}\right)$$

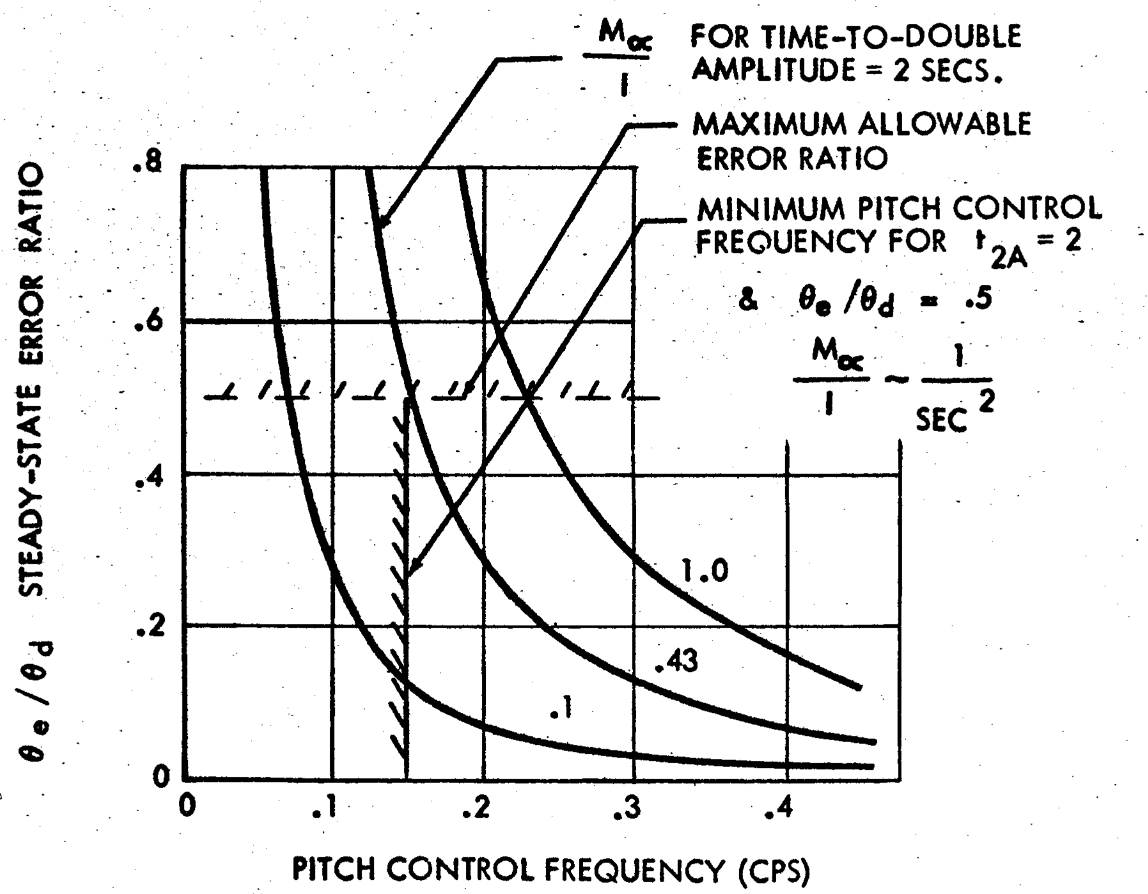


Fig. IV A4-4 DETERMINATION OF MINIMUM PITCH CONTROL FREQUENCY

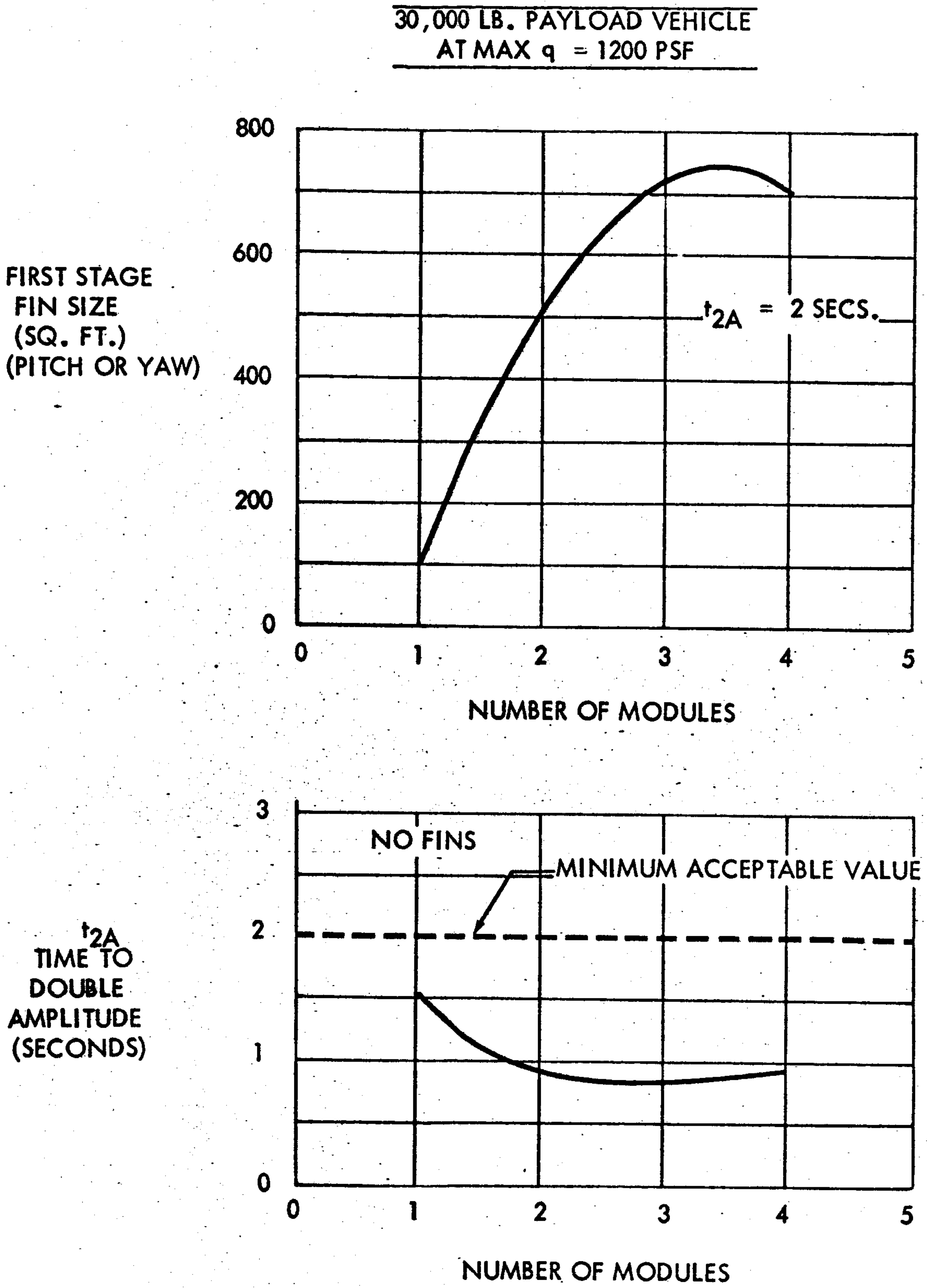


Fig. IV A4-5 EFFECT OF FIRST STAGE CONFIGURATION ON FIN SIZE AND t_{2A}

Increasing the number of first-stage motors increased vehicle instability through a combination of rearward shift in center of gravity, increased normal force, and lowered inertia. Consequently, the single-motor configuration with its lower instability and longer moment arm required the least fin area to achieve the required stability criterion. For this reason it was chosen for the 30,000-pound-payload vehicle.

Configuration Flexibility and Fineness-Ratio Considerations

Booster first-mode body-bending frequency was calculated for the various payload boosters, and was found to be low for these configurations. Figure IVA4-6 compares the bending frequencies with the minimum-pitch frequencies. The ratio between the two is approximately 5, which is at the lower limit of the desirable range of ratios between 5 and 10. As compared to the present liquid boosters, this is due primarily to differences in payload, L/D (vehicle fineness ratio), and clustering (method of attachment of motors). Only a small amount of the difference appears to be due to the solid motor itself, which causes an increase in the mass distribution at the rear. Possible steps to alleviate this problem are to configurate to a lower vehicle L/D, increase stiffness, and/or reduce the pitch-control frequency by providing more inherent stability through increased fin size.

Of these three methods, the vehicle L/D appears to be the most powerful, although the latter two may also be required. The effect of vehicle L/D was investigated on frequency ratio, fin size, and control-system impulse as shown in Figure IVA4-7. A reasonable compromise between control requirements and frequency ratio appears to be in the L/D region of 8.

Thrust-Vector-Control Method

Because of the broad nature of the present study, no attempt was made to optimize a thrust-vector-control system for the configurations. A brief review was made of the various methods considered for solid motors and a few preliminary

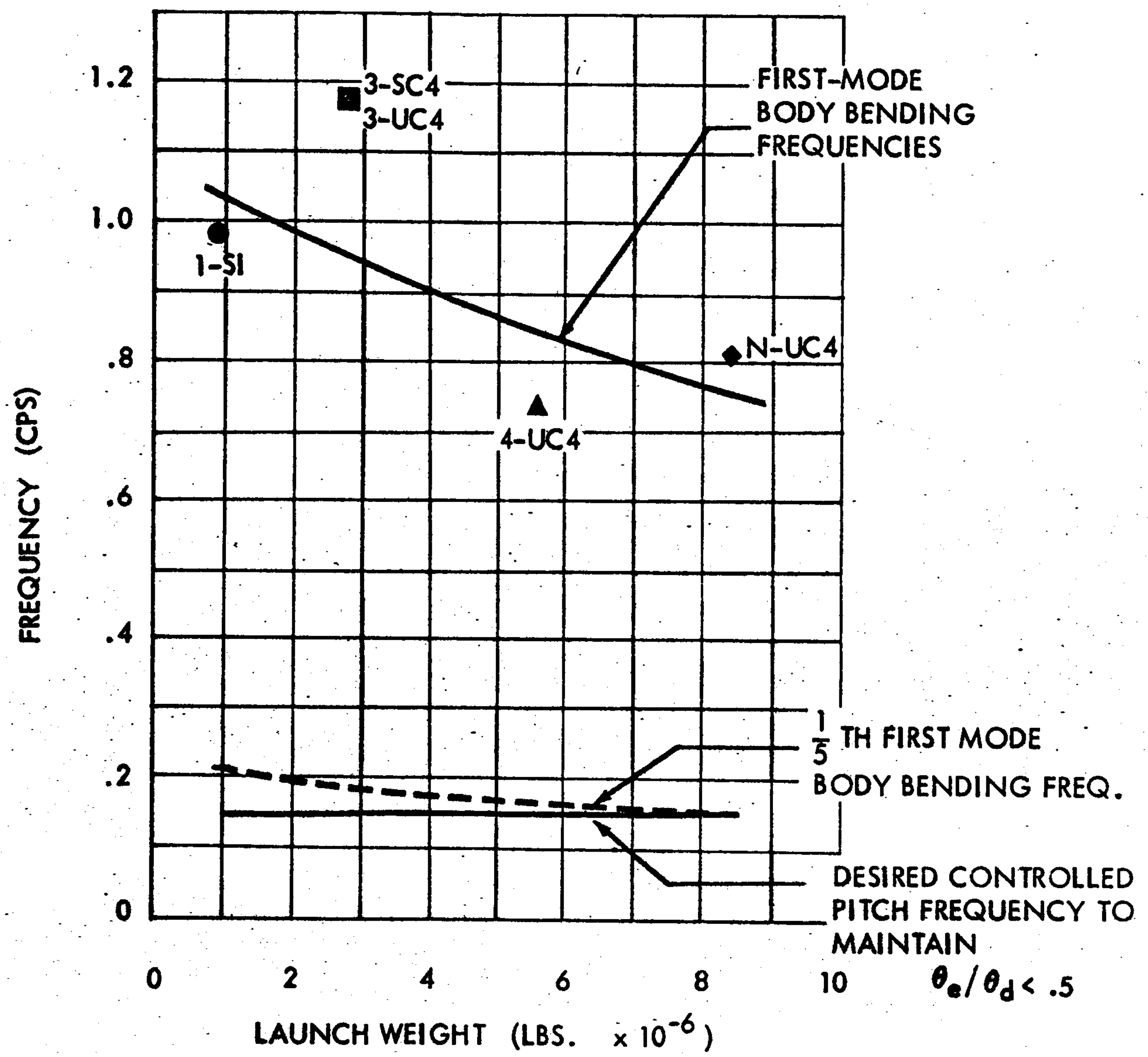


Fig. IV A4-6 VEHICLE CONTROL FREQUENCY REGIMES

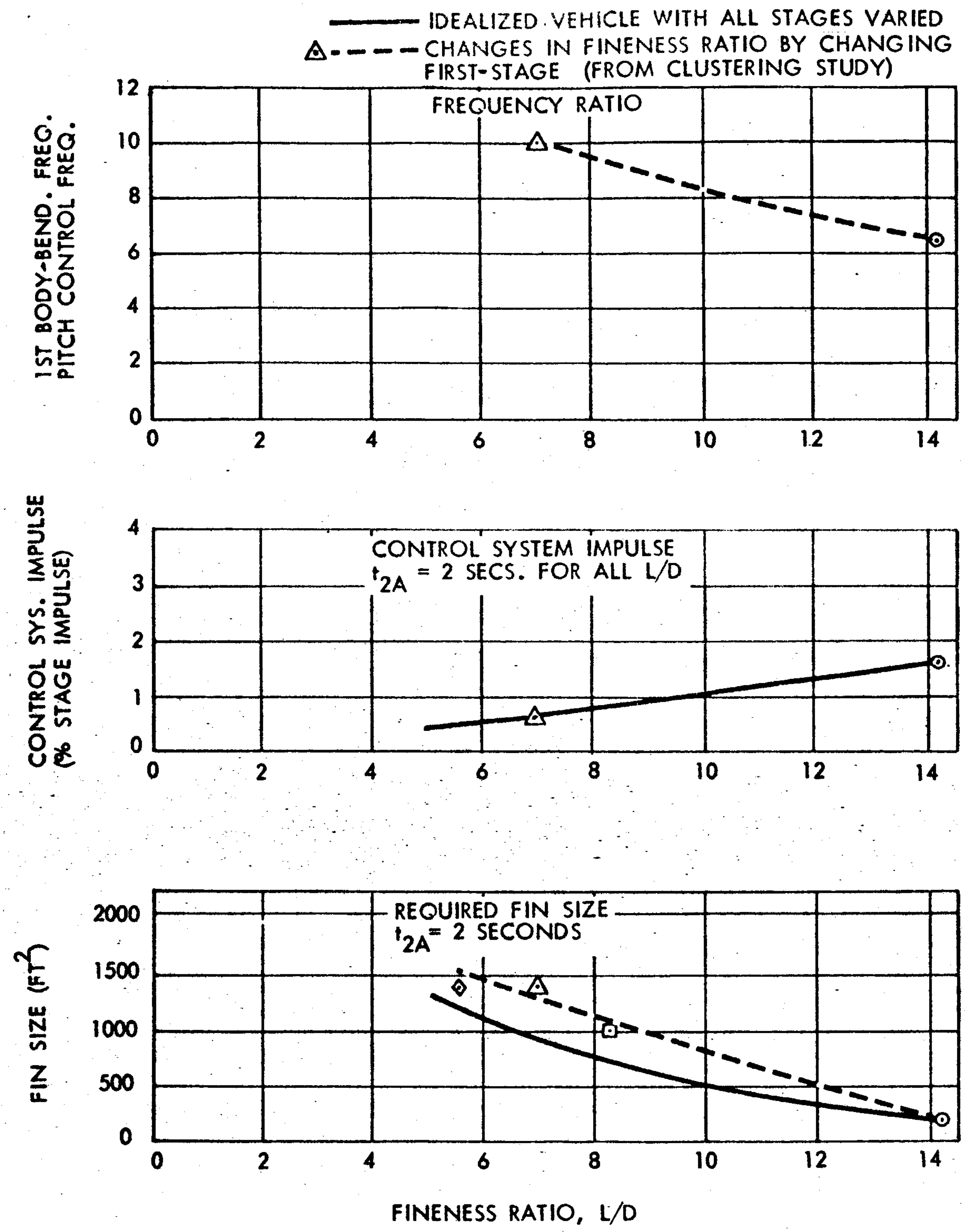


Fig. IV A4-7 EFFECT OF FINENESS RATIO ON CONTROL CHARACTERISTICS

30,000-POUND PAYLOAD BOOSTER

conclusions drawn. The movable nozzle appears to be an obvious choice from the standpoints of simplicity, efficiency, and control capability. However, at present, it requires further study and development for the long burn times of the advanced solid motor because of the gimbaling seal and general materials problem. An additional disadvantage is that of having to fire a main-stage motor for each test of the system.

The two methods most widely considered as currently feasible are the fluid-injection system and the auxiliary-control motor system. Both methods require large quantities of stored propellant, gas or liquid, and hence place large weight penalties on the first-stage booster. The design of either system requires a detailed trade between system weight, vehicle fin size, control law, and control impulse required to attain the maximum performance. A detailed system layout is required to ensure reasonable control-system size compatibility with the booster and to determine overall system complexity. Neither system appears attractive unless control deflections and total impulse can be kept to low values. A general summary of system characteristics for the three systems is presented in Table IVA4-1.

For the present study, fluid injection was chosen as a representative, currently feasible system and was used on all vehicles. A detailed study of system requirements and vehicle dynamics is required to attain the optimum match between a given system and the configuration with which it is used.

Table IVA4-1

COMPARISON OF THRUST-VECTORING SYSTEMS

	Method	Fluid Injection	Auxiliary Rotating Solid Rockets	Movable Nozzles
Control-System Performance	Effect on Boost Performance	Loss in I_{sp} from 240 to 233	Moderate: Additional thrust compensates in part for high system weight	Negligible
	Control Efficiency	Fair: maximum control deflection on the order of 2°	Fair: high rotating rates required	High
	Critical Sizing	Total impulse required or maximum control deflection	Total impulse required and actuation power requirements	Actuator requirements and maximum deflection angle
	Stage Separation	Control forces decay as thrust decays	Control forces can be maintained throughout thrust tail-off	Control forces decay as thrust decays but may possibly be maintained by higher deflections
Complexity		Fair: large number of valves, plumbing, and storage components	Medium	Low
Design Feasibility		Good: requires large quick-acting valves	Fair: requires large volume for mounting	Considered questionable for long burn times
Problem Areas		Valve design Requires main-stage firing for test	90° corner in motor nozzle Large power actuation requirements	Materials and nozzle seals Requires main-stage firing for test

5. WEIGHTS

SUMMARY AND CONCLUSIONS

To describe the performance and for the cost evaluation of two-stage solid/liquid vehicles, emphasis was necessarily placed on the total vehicle. Hence, both the oxygen/hydrogen upper stages and the solid-propellant lower stages have been subjected to the same degree of weight analysis. This section describes the criteria and considerations used for weight analysis of all components of both the solid and liquid stages.

Through weight analysis of detail components, mass-fraction data were established for performance determination. A summary of the calculated mass-fraction data is shown in Figures IVA5-1 and IVA5-2 for solid and liquid stages, respectively. Detail weight statements used for system cost estimating may be found in Sections B, C, D, E, F, and G for the various vehicles considered.

Although weight analysis is accurate enough to describe vehicle sizes and to evaluate system feasibility, it is recognized that several subsystem areas require additional investigation to provide an accurate description from the weight standpoint. With regard to the solid-propellant stages, these areas are discussed below.

Thrust Vector Control (TVC) Concept

The secondary liquid-injection system contributes a considerable portion of the stage inert weight. Other TVC concepts should be investigated for feasibility and for weight reduction. Should secondary liquid injection still appear desirable, it is recommended that this system be thoroughly analyzed, especially with regard to injectant storage pressure and injectant delivery concept.

Nozzles

An attempt to correlate industry nozzle-weight data was unsuccessful due to large weight discrepancies. It has been necessary to develop analytical nozzle-weight

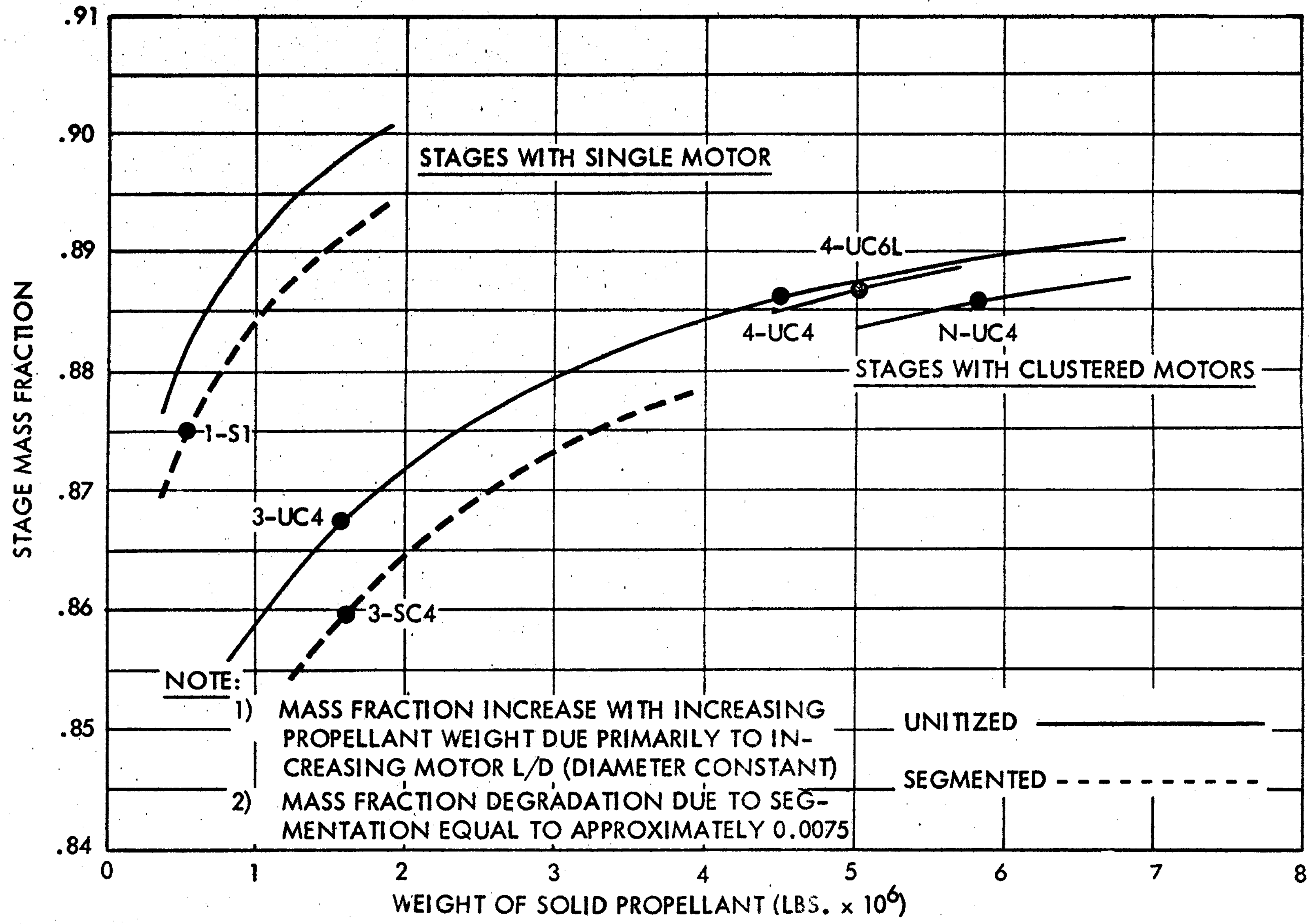


Fig. IV A5-1 MASS FRACTION OF SOLID PROPELLANT STAGE

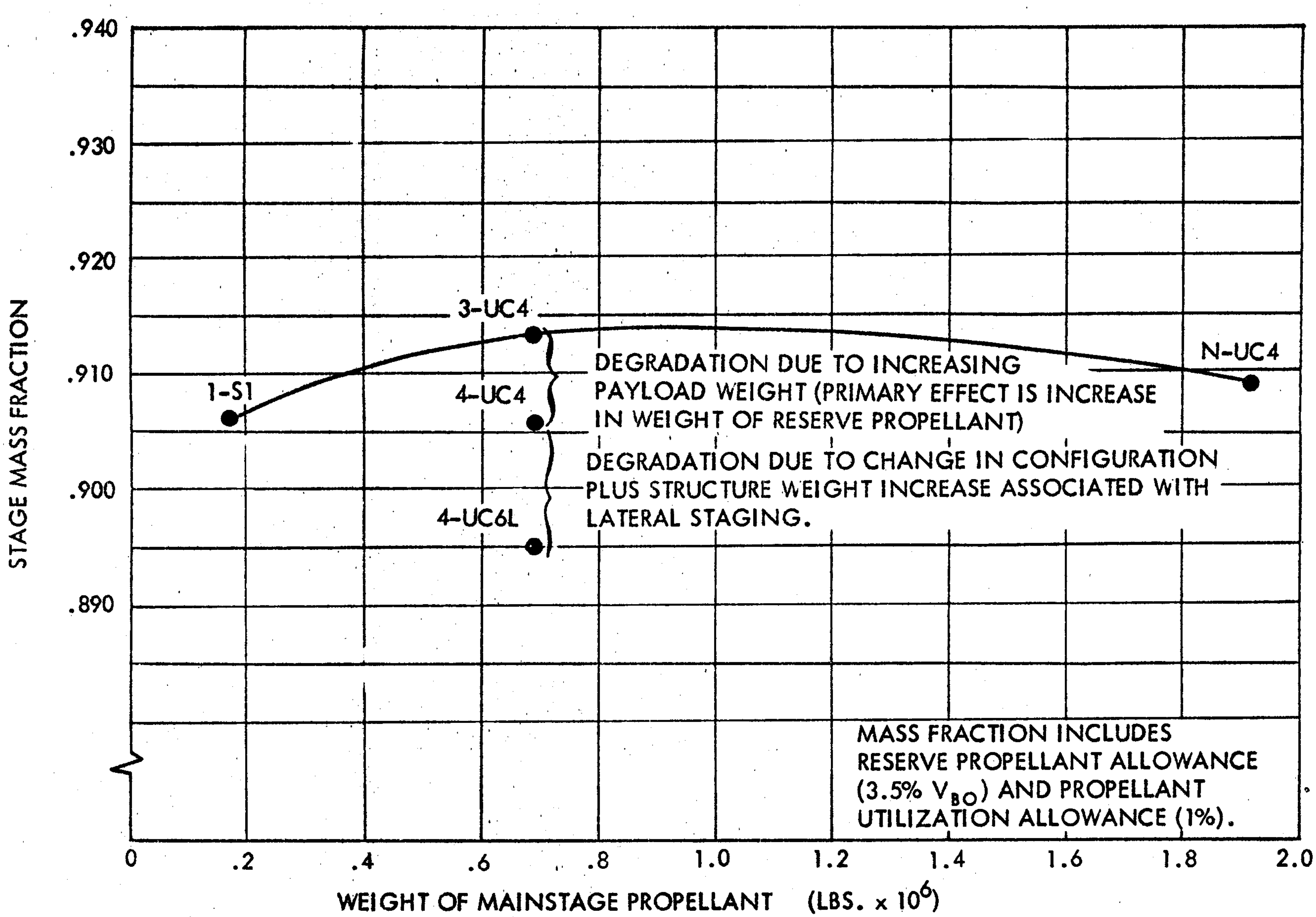


Fig. IV A5-2 MASS FRACTION OF OXYGEN-HYDROGEN STAGE equations with a minimum of substantiating actual data. It is anticipated that this condition will become less acute in the near future as results of test firings (completed or under way) are integrated into the development of flight-weight nozzles. If the thrust-vector-control concept is secondary liquid injection, it is recommended that an attempt be made to establish the nozzle-weight effects associated with the maximum side-force requirements and with increased local erosion.

Insulation of Segment-Type Joints

The weight allowance for insulation of segment-type joints is a significant portion of the segmenting weight penalty. In development of the segmentation joint, attention must be paid to insulation as well as joint hardware. Heat-transfer conditions in the joint area and the heat-sink capability of the joint must be established by test before confidence in the weight estimation will result.

Clustering Structure

Considerable analytical study of the clustering-structure problem gives moderate confidence in the weight estimates for clustering. Additional development through study and testing is necessary to evaluate fully the weights of clustered concepts.

Propellant Sliver Allowance

Sliver allowances are very dependent on the internal ballistic characteristics and the staging concept. Very little data are available on the tail-off characteristics or the difference between unitized and segmented designs. Further analysis of specific configurations is recommended to evaluate propellant sliver allowance accurately.

With regard to the cryogenic upper stages, two areas need further investigation from the standpoint of weights.

Y-1 Engines

A weight of 0.007 pound per pound of thrust has been used for the wet Y-1 engine package based on preliminary estimates by the Aerojet-General Corp. A review of the weight trends of the H-1, F-1, and J-2 engines shows weight growth during development that would indicate operational Y-1 engine weight of approximately 0.010 pound per pound of thrust. Further investigation of Y-1 engine weight seems warranted.

Propellant-Utilization (PU) Allowance

A NASA requirement in this area is that, for four or less engines, the weight ratio of PU allowance to mainstage propellant be 1.0 per cent. Boeing studies for large oxygen/hydrogen systems indicate that a PU allowance of 0.5 per cent should be sufficient for preliminary weight-analysis purposes. Further review of PU allowance and propellant reserves is warranted.

PURPOSES

During Phase II, the primary objective of weight analysis was: to establish stage mass fractions for performance calculations; to provide detail stage weight statements as an aid to cost evaluation; and to identify areas requiring additional investigation from the standpoint of weights.

WEIGHT ANALYSIS

Solid-Propellant Stages

For weight-analysis purposes, the inert weight of each solid-propellant stage has been divided into the following summary categories: basic motor; thrust-vector-control system; equipment; structural provisions; separation rocket; and unusable propellant residuals. Each of the above categories was further divided into more detailed component parts. Each component was investigated and preliminary analysis was made for determining its weight.

Table IVA5-1 summarizes the primary criteria used for weight estimating. The components and the weight analysis considerations are described in the following paragraphs.

Table IVA5-1

PRIMARY CRITERIA USED FOR WEIGHT-ESTIMATING PURPOSES, SOLID-PROPELLANT STAGE

Structures:	
Case Material	Steel
Case Ultimate Tensile Strength, psi	200,000
Motor Nominal Operating Pressure, psia	800
Case Ultimate Design Pressure, psia	1,330
Segment Joint Concept	Tapered Pin
End Burning Over Segment Joints	Yes
Control:	
$\frac{\text{Total Impulse, TVC}}{\text{Total Impulse, axial}}$, Maximum	0.015, excluding config. N-UC4 0.010, config. N-UC4
Thrust-Vector Control:	
General Concept	Secondary Fluid Injection
Injectant	Fe113, excluding config. N-UC4 N_2O_4, config. N-UC4
Injectant Delivery Concept	H_e gas blowdown*
Residuals:	
Residual Injectant, % of "expended injectant"**	10
Sliver Allowance, % of solid propellant	0.25 segmented 1.00 unitized
Miscellaneous:	
Separation (retrorocket requirement)	1.0 g for 3 sec
Thrust-Termination Provisions	None

* Initial conditions of H_e gas are 5,000 psia and 70°F

** "Expended Injected" is injectant required to deliver the maximum TVC Total impulse

Basic Motor

Motor Case—All the motor cases are cylindrical with 1.4/1 elliptical bulkheads. Case volume is based on a solid-propellant density of 0.064 pound per cubic inch and the volumetric efficiencies given in Table IVA5-2.

Table IVA5-2

MOTOR VOLUMETRIC EFFICIENCY

PAYLOAD WEIGHT (LBS)	CONFIGURATIONS	MOTOR VOLUMETRIC EFFICIENCY - % FORWARD HEAD	CYLINDER	AFT HEAD
30,000	1-S1	90	84	60
100,000	3-SC4	90	84	60
100,000	3-UC4	83	83	83
180,000	4-UC4	83	83	83
180,000	4-UC6L	83	83	83
350,000	N-UC4	83	83	83

Shell thicknesses of the motor case are calculated from pressure-design requirements, and consideration for local structural provisions. The case is constructed of steel and is ultimate-strength-critical at 200,000 psi. The nominal operating pressure for the motor is 800 psia and the ultimate design pressure used for weight analysis is 1330 psia. The ultimate design pressure was based on a design-pressure factor of 1.19 and an ultimate factor of safety of 1.40.*

Motor-case weights include local structural provisions as described below:

1) An extension of both ends of the cylinder for handling and structural attachments provisions;
2) A joint on the aft bulkhead for nozzle attachment and propellant porting purposes;
3) A local buildup of the bulkhead shell for carrying thrust loads in addition to pressure loads (it is interesting to note that the above structural provisions result in the aft bulkhead weighing approximately 50 percent more than the forward bulkhead).

* Follow-on study indicates a pressure-design factor of 1.23 and, hence, an ultimate design pressure of 1378 psia.

It has been assumed that the motor cases may be heat-treated such that no weight penalty is incurred at welded joints.

Nozzle—Design analyses of large nozzles for the thrusts and burn times proposed in this study are limited. A review of available industry data on nozzle weight of large solid propellant motors provides large weight discrepancies and inconclusive trends.

Because of the inconsistency of data, Boeing has performed considerable study of nozzle weight trends. For analysis purposes, the total nozzle weight was divided into three categories: shell; throat; and insulation weight. A general equation was developed for each category. The equation considers the influence of chamber pressure, specific impulse, expansion ratio, and burn time. The summation of these three equations is plotted in Figure IVA5-3 and represents fixed-nozzle weight trends for large solid-propellant motors as a function of motor thrust.

Case Liner—For weight-analysis purposes, it was assumed that the motor case is lined with a 0.10-inch-thick rubber-based material (density equals 0.042 pound per cubic inch) to provide case bonding of the propellant. The forward and aft bulkheads also have this liner in addition to the internal insulation described below.

Internal Insulation, Bulkheads—The forward and aft bulkheads are assumed to be lined with a phenolic-based internal insulation. Its density is 0.063 pound per cubic inch. Insulation thickness of the forward bulkhead is 0.10 inch. Insulation thickness for the aft bulkhead was calculated at 2 inches at the nozzle boss, decreasing to 0.10 inch at the bulkhead/cylinder junction.

Insulation weights for the forward and aft bulkheads of the 13.3-foot-diameter cases are 200 and 1600 pounds, while the weights for the 16-foot-diameter cases are 300 and 2400 pounds, respectively. Note that the aft-bulkhead insulation weight is eight times the forward-bulkhead insulation weight.

Igniter and Safe/Arm Unit—Igniter weight is based on igniter propellant, igniter inerts, and a safe/arm unit. For analysis purposes, a weight ratio of igniter pro-

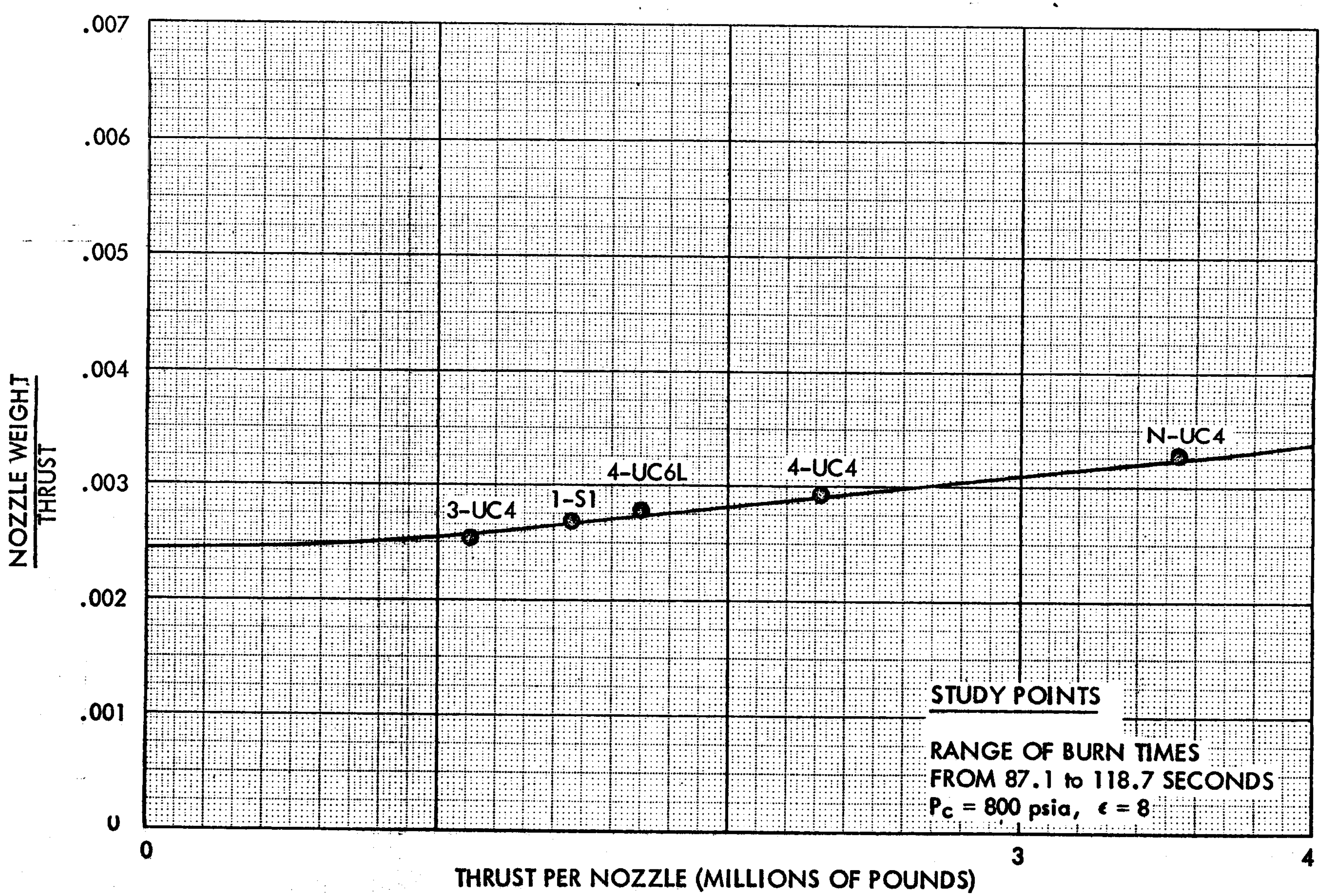


Fig. IV A5-3 FIXED NOZZLE WEIGHT TREND

pellant to main stage propellant was established at 0.04 percent. Igniter inerts were defined by a mass fraction of 0.60 for a small igniter (igniter propellant weight of 200 pounds) and 0.75 for a large igniter (igniter propellant weight of 2500 pounds). Since the igniter propellant is consumed prior to launch, it is excluded from the stage inert weight.

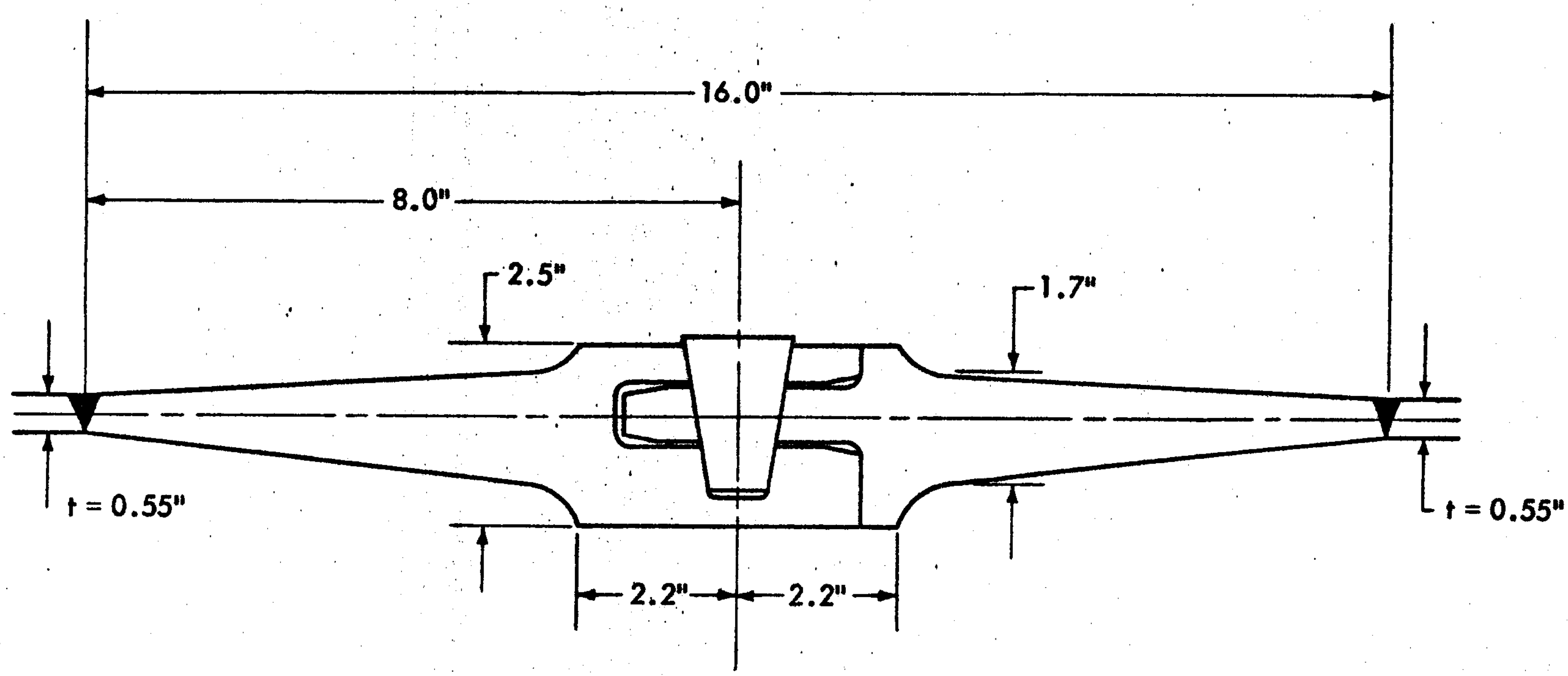
Segment-Type Joints—The joint concept selected for segmented motors is the tapered-pin joint proposed by Grand Central Rocket Co. This segment-joint concept, shown in Figure IVA5-4, weighs 2010 pounds (exclusive of insulation) per joint for a motor-case diameter of 160 inches and for a nominal design pressure of 800 psia. The weight penalty for this segment joint is based on a cross-sectional area increase of (50) $(t_{motor\ case})^2$ as shown in Figure IVA5-4.

Internal Insulation Segment-Type Joints—The Segmentation concept employed allows end-burning of propellant at the segment joints. The joint and motor case is therefore progressively exposed to high temperature for a distance on each side of the joint equal to the propellant web thickness.

Although definite conclusions as to the heat-transfer conditions in this area are not established, it is recognized that insulation is required. A weight allowance for phenolic-based insulation has been applied. The insulation is assumed to be 1-inch thick over the joint and tapers to 0.1 inch at a distance equal to the web thickness on each side of the joint. This insulation for the 13-foot-diameter motors weighs 1390 pounds per joint.

Thrust-Vector-Control System

Thrust-vector-control is accomplished by secondary fluid injection into the fixed nozzles. Freon is used for all vehicles except configuration N-UC4, which uses N_2O_4 for the secondary fluid. The total required weight of injectant is based on preliminary estimates of the maximum total impulse ratio requirements as shown in Table IVA5-3. The 1-S1 vehicle, which is a single-motor stage, requires a separate roll-control system using hydrogen peroxide.



TOTAL AREA BETWEEN WELDS = 80 t^2_{case}

CASE AREA BETWEEN WELDS = 30 t^2_{case}

JOINT AREA BETWEEN WELDS = 50 t^2_{case} (Use for weight estimating purposes)

Fig. IV A5-4 SEGMENT-JOINT CONCEPT

Table IVA5-3

CONTROL FORCE MAXIMUM TOTAL IMPULSE REQUIREMENTS

MAXIMUM TOTAL IMPULSE, CONTROL / TOTAL IMPULSE, AXIAL *

Configuration	Pitch & Yaw**	Injectant	Roll	Prop.
1-S1	1.5 %	Freon	0.20 %	Hydrogen Peroxide
3-SC4	1.5 %	Freon	-	-
3-UC4	1.5 %	Freon	-	-
4-UC4	1.5 %	Freon	-	-
4-UC6L	1.5 %	Freon	-	-
N-UC4	1.0 %	Nitrogen Tetroxide	-	-

* Specific Impulse (side):

Freon 100 sec
Nitrogen Tetroxide - 140 sec

** Follow-on Study Indicates:

1.6%, 1-S1 and 4-UC4
1.68%, 3-SC4 and 3-UC4
1.9% 4-UC6L
1.0% N-UC4

The total installed injection fluid includes a 10-percent allowance above maximum requirements. This allowance is carried as residual fluid weight.

Weight analysis is based on the use of helium as the pressurant to expel the injection fluid. The helium is stored in spherical tanks at 5000 psia and 70°F. During blowdown, the pressure and temperature reduce to 2000 psia and -100°F, respectively. The injectant is stored in spherical bottles at 1600 psia and 70°F. Figure IVA5-5 shows the weight of TVC hardware as a function of injection-fluid weights. The tankage material is titanium and is designed to an ultimate allowable of 130,000 psi with a 2.5 factor of safety.* Table IVA5-4 tabulates the weight of hardware components as a function of injection-fluid weight.

* Follow-on study indicates 120,000 psi

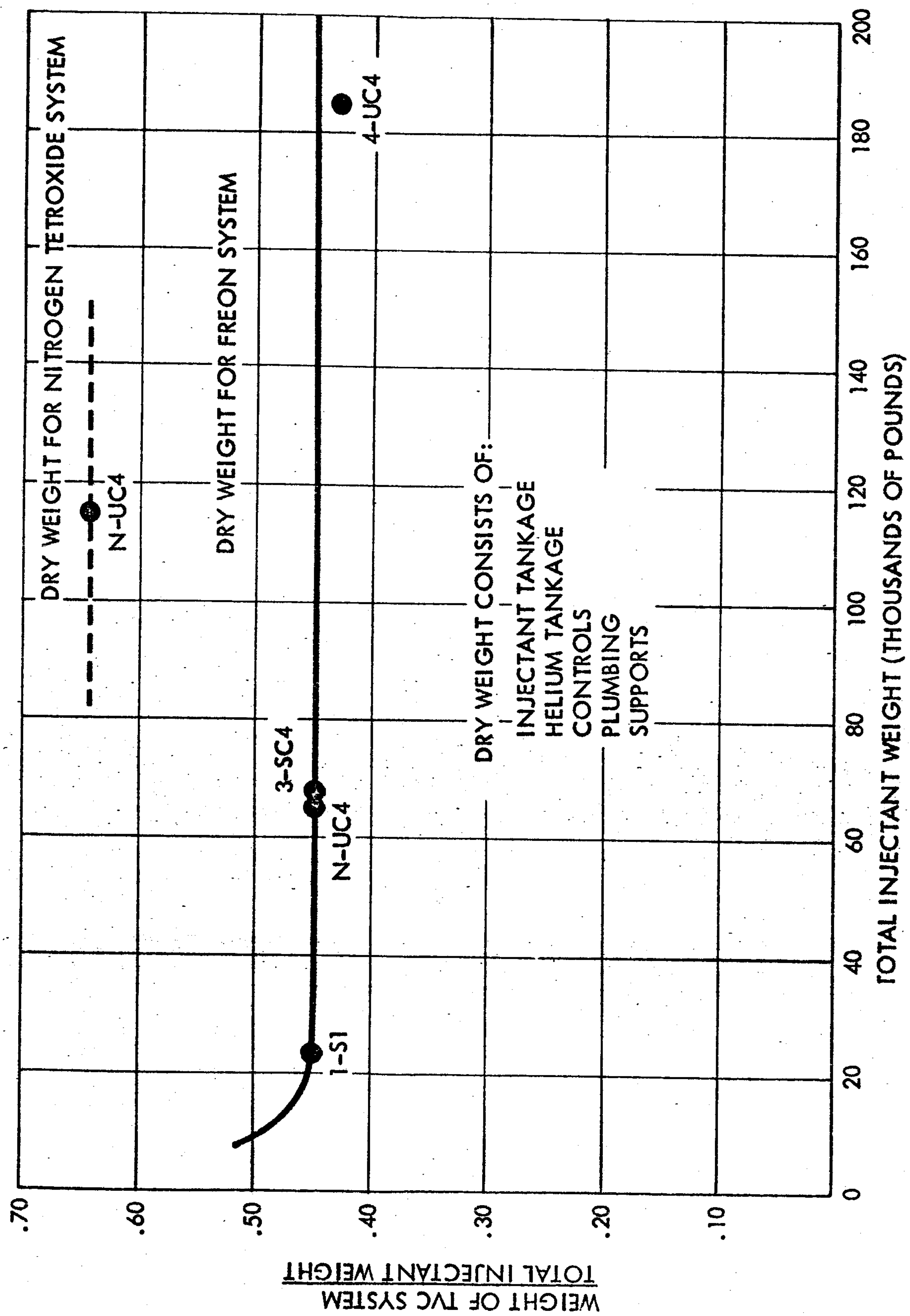


Fig. IV A5-5 WEIGHT OF THRUST VECTOR CONTROL SYSTEM

Table IVA5-4

COMPONENT WEIGHTS AS A FUNCTION OF INJECTANT WEIGHT

INJECTANT	FREON	NITROGEN TETROXIDE
Weight of Injectant Tankage	9.9%	14.2%
Weight of Helium Gas	2.2%	3.1%
Weight of Helium Tankage	29.3%	42.0%

It may be noted that the final configuration analysis showed that spherical Freon tanks may not be accommodated around the nozzles due to space limitations. Use of a cylindrical Freon tank as shown would increase Freon tank weight approximately 35 percent.

Final configuration drawings also reflect a change in the concept of Freon pressurization. The revised concept would use a hydrazine-gas generator. This system would offer a large reduction in the weight required for expulsion of the injectant fluid but would have the attendant problems of the hot-gas system that need further investigation.

Equipment

Because equipment weight is relatively small, very little further weights analysis has been performed during Phase II.

The stage equipment consists of: control elements; telemetry system; environment-control provisions; power supply; electrical network; and, for single-motor stages, a roll-control system. Control elements are the rate gyros and accelerometers, which are part of the vehicle guidance and control system. The telemetry system consists of telemeter sets, sensors and transducers, electrical wiring, and all other components required for transmission of data. Environment-control provisions are the structural provisions (ducting, baffles, and connectors) required for transmission of the cooling and ventilating gases to the equipment cannisters during the prelaunch period. The power supply consists of batteries for providing electrical power to the thrust-vector-control system, the separation devices, and the telemetry system. The electrical network includes an inverter, voltage regulator, umbilical connectors, wires, raceway with thermal protection, and other miscellaneous components. For the single-motor stages, a roll-control system is provided. This system consists of a high-pressure tank for helium gas, a tank for storage for the hydrogen peroxide, and the necessary controls, plumbing, and supports.

Weights for the items comprising stage equipment are based on a combination of past experience and study data. The calculated weights, which are a function of stage configuration, fall within the limits as presented in Figure IVA5-6.

Structural Provisions

The structural provisions for a solid first stage consist of forward interstage, aft skirt, fins, base-heat protection, separation structure, and, when applicable, clustering structure.

Forward Interstage—The forward interstage is an aluminum semimonocoque shell design. Its primary function is the transmission of loads between stages. The upper end of the interstage attaches to the aft skirt of the liquid stage. The lower end attaches to a cylindrical skirt extension of the solid-motor case for a single motor and to a stiffened barrel section for the clustered vehicles. For weight-analysis purposes, the interstage is designed for the axial loading condition at stage burnout.

Aft Skirt—The aft skirt is an aluminum semimonocoque design. It is designed for support on the launch pad with ground-wind loads. Ground reactions are sheared into this skirt through tapered longerons.

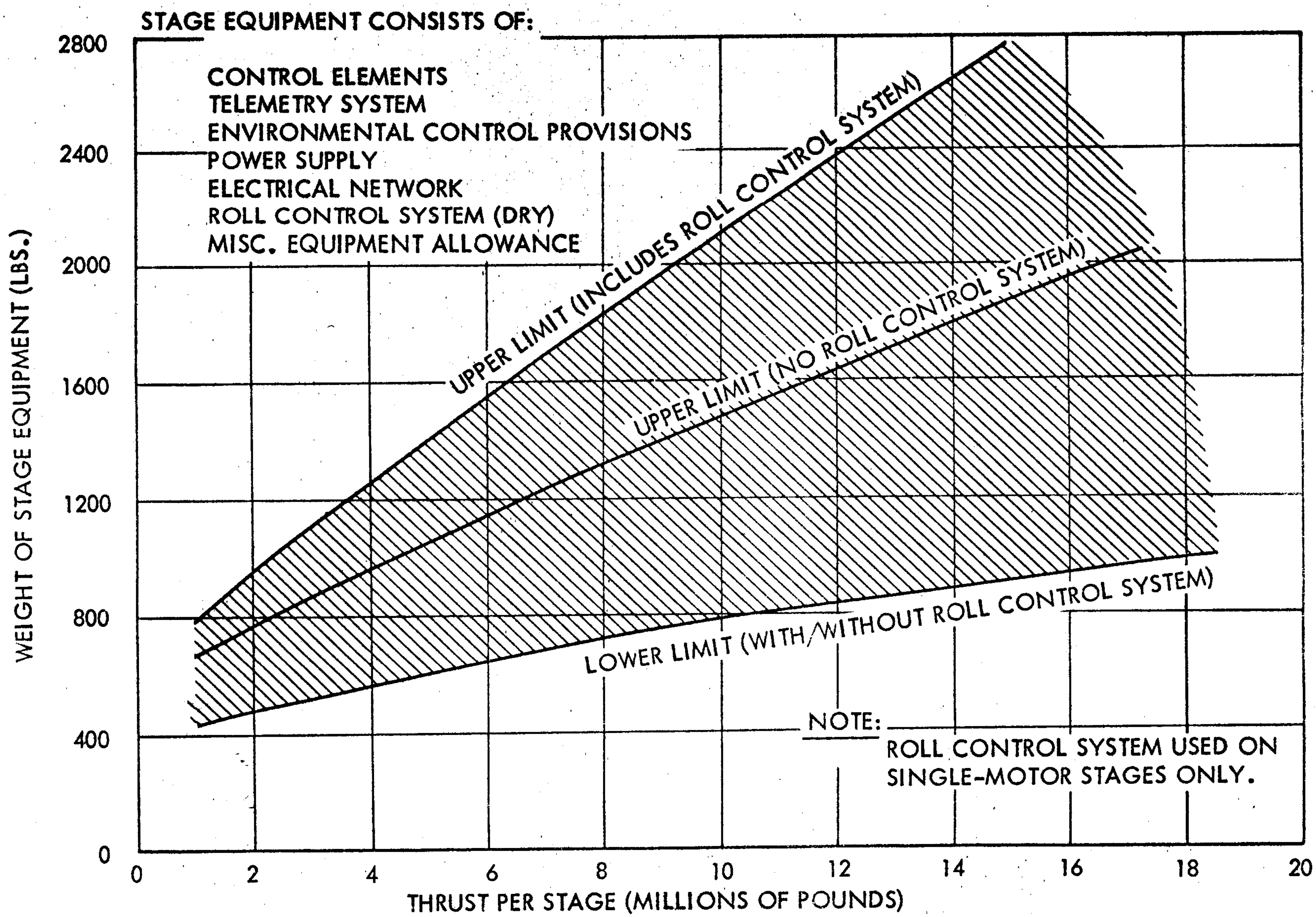


Fig. IV A5-6 WEIGHT TREND FOR STAGE EQUIPMENT

Fins—Fins are sized to limit time-to-double-amplitude to 2 seconds at maximum dynamic pressure. Fin weight is approximately 5.5 pounds per square foot plus a 20-percent allowance for attachment provisions.

Base-Heat Protection—The function of the base-heat insulation and shielding is to protect structure and equipment from flame excursions, convection, and radiation forward of the nozzle exit plane.

Based on limited design criteria,it was assumed that an insulation blanket using cork is applied over the aft bulkhead, internal surface of the skirt and over critical components located in the base area. For clustered configurations, a steel flame shield with an ablative coating is located at the nozzle exit plane.

Separation Structure—Stages may be separated by one of several techniques (tension bands, explosive bolts, shaped charges, etc.). Design studies have indicated that the weights of stage-separation provisions are small. Typical weight allowances were used in this study.

Clustering Structure—Clustering structure is defined as those structural components not normally present on the basic motor, but required to join two or more motor cases into a structural unit. All clustering-structure components are aluminum. The clustering structure is primarily located at the forward end of the first-stage motor. The lower open end of a stiffened barrel section is attached to an upper-skirt extension of the cylindrical motor case. The upper open end of the barrel section is attached to the forward interstage and provides a cavity for the insertion of the second-stage nozzle and thereby reduces interstage length and weight. The barrel section has interior rings at the upper and lower ends that are tied by an exterior, rigid, truss-beam network to the other barrel sections.

Motor cases are tied at the lower end of the stage by fittings which allow longitudinal movement between motors but restrict lateral movement.

For weight-analysis purposes, the clustering structure was investigated to determine the size of truss-beam member and barrel-section thickness due to expected loading conditions. Results of the clustering-structure study indicate weight trends as presented in Figure IVA5-7.

Separation Rockets

Separation rockets ensure that the acceleration of separated first stage will not interfere with the upper stage after staging. These rockets were sized to provide 1 g of acceleration for 3 seconds. Small solid-propellant rockets, having a specific impulse of 250 seconds and a mass ratio of 0.75, were assumed. An additional 10 percent of the separation-rocket weight was provided for attachment.

Unusable Propellant and Residuals

Unusable propellant and residuals consist of propellant slivers, residual TVC injection fluid, and the pressurization gases that expel the TVC fluid.

The propellant sliver is assumed to be 0.25 percent for segmented motors and 1 percent for unitized motors.

The residual TVC fluid is 10 percent of the injected fluid.

The weight of pressurization gases that expel the TVC fluid is based on the use of helium. As discussed under Thrust-Vector Control, the weight of helium is 2.2 percent of the Freon weight and 3.1 percent of the nitrogen-tetroxide weight.

Oxygen/Hydrogen Stages

For weight-analysis purposes, the inert weight of each oxygen/hydrogen stage has been divided into the following summary categories: structure; propulsion system and accessories; equipment; unusable propellant and gas residuals; usable propellant residuals; and items expended prior to ignition. Each category was further divided into more detailed component parts. Each component was investigated and a preliminary analysis was made for determining its weight.

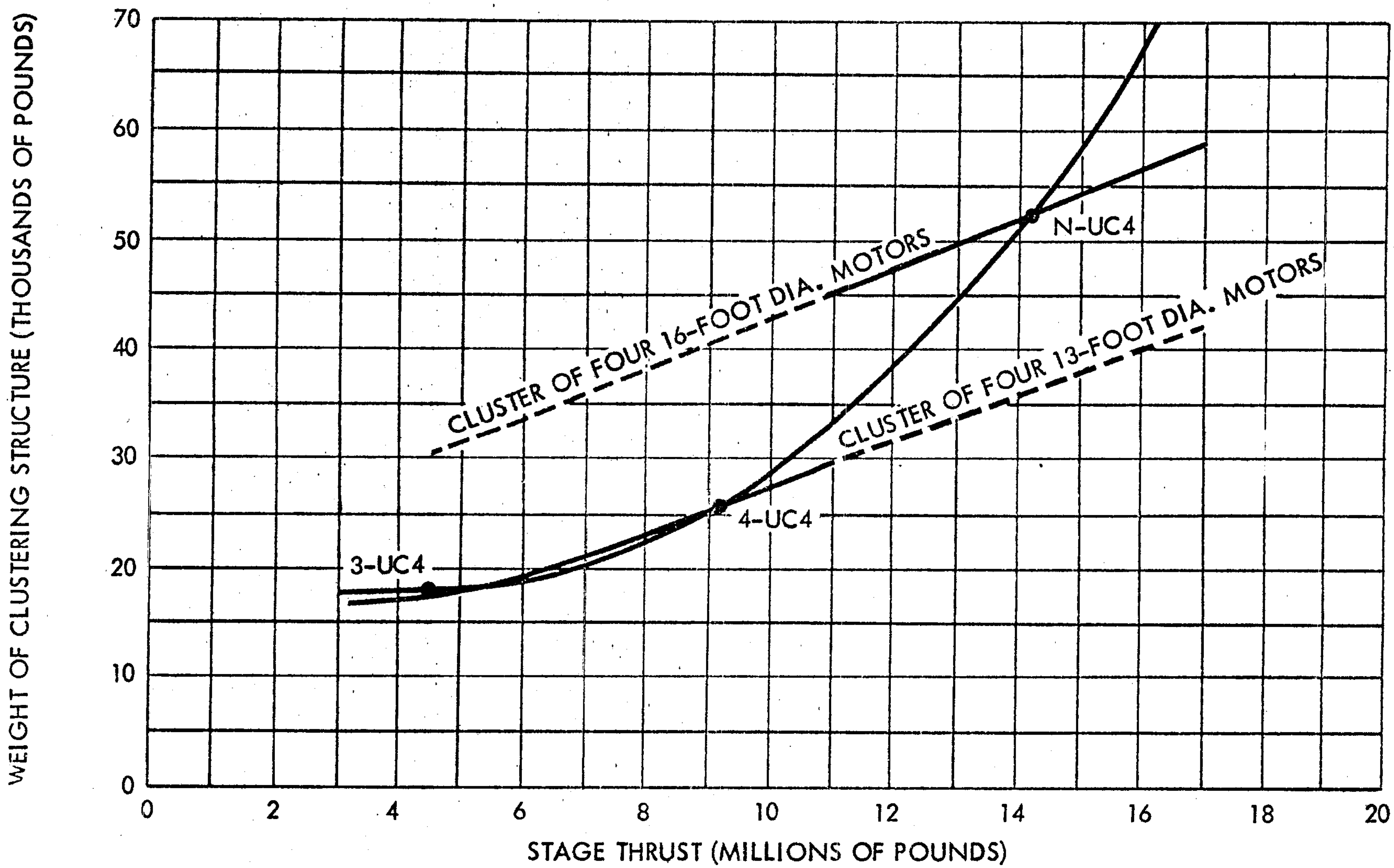


Fig. IV A5-7 CLUSTERING STRUCTURE WEIGHT TRENDS

Table IVA5-5 summarizes the primary criteria used for weight-estimating purposes. A description of the components and of the weights-analysis considerations is provided in the following paragraphs.

Structure

Tankage—The stage tankage is cylindrical with 1.4/1 elliptical-end bulkheads. The oxidizer is located aft and is separated from the fuel by a hemispherical bulkhead. End bulkheads are constructed of aluminum sheet, side walls are aluminum waffle, and the intermediate bulkhead is a sandwich having aluminum faces and a fiberglass core. Ullage pressures in both the fuel and oxidizer compartments are 15 psia during the holddown period. Just prior to launch, the ullages are charged with cold helium gas to increase ullage pressures in the fuel and oxidizer compartments to the desired flight values of 27 and 32 psia, respectively.

Weights for the end bulkheads are based on shell thicknesses as determined by maximum local pressure-design requirements at first-stage burnout. Sidewall weight is based on shell thicknesses as determined by local pressure-design requirements at first-stage burnout, and on local waffle stiffening requirements as determined by the ground-wind condition. Weight of the intermediate bulkhead is based on face thickness and core requirements as determined by a prelaunch pressure-loss condition during which the ullage pressure in the oxidizer compartment suddenly decreases from 32 to 15 psia, while the ullage pressure in the fuel compartment is 27 psia. (The resulting collapse-pressure loading on the bulkhead is 12 psi plus the static head of the fuel.) Also, weight allowances are provided for access provisions and sump attachment structure.

The tankage is constructed of aluminum that is yield-strength critical at 52,000 psi, and is designed to a yield factor of safety equal to 1.10. Ratios of tankage weight to the total weight of propellant are approximately 1.9 to 2.3 percent for the oxygen/hydrogen stages under consideration.

Table IVA5-5

PRIMARY CRITERIA USED FOR WEIGHT-ESTIMATING PURPOSES, OXYGEN/HYDROGEN STAGES

Configuration:	
Oxidizer Location	Aft
Structures:	
Tank Material/Construction	Aluminum/Waffle
Tank Yield Tensile Strength, psi	52,000
Yield Factor of Safety	1.1
Weight of Tank Insulation System, psf	0.40
Propulsion:	
Engines	J-2, Y-1
Fuel Pump Nominal NPSH Requirement, feet	325
Oxidizer Pump Minimum NPSH Requirement, feet	25
Boost Pumps	No
Fuel-Container Ullage Pressure, psia	27
Oxidizer-Container Ullage Pressure, psia	32
Pressurization Concept	Bleed: 160 °R GH_2 over LH_2 270 °R GO_2 over LO_2
Ullage-Rocket Requirement	0.1 g for 5 seconds
Separation-Rocket Requirement	1.0 g for 3 seconds
Residuals:	
PU Allowance, % Main-stage Propellant Weight	1.0 (four or less engines)
Reserve Propellant, % Change in Burnout Velocity	3.5

<u>Antislosh and Vortex Provisions</u>—Antislosh and vortex provisions consist of an antislosh cylinder and egg-crate type, antivortex provisions. The antislosh cylinder has a diameter equal to 70 percent of the tank diameter, and extends

from end bulkhead to end bulkhead. The cylinder is light gage, beaded, frame-stiffened, and has 30 percent of its surface area cut out as lightening holes. The egg-crate antivortex structure is light gage, has a 12-inch by 12-inch cell size, has 30 percent of its surface area cut out as lightening holes, and has a depth equal to half of the bulkhead height.

Weights for the slosh cylinder in the fuel compartment vary from 0.17 psf for a 160-inch-diameter compartment to 0.23 psf for a 396-inch-diameter compartment. The corresponding unit weights for the slosh cylinder in the oxidizer compartment are 0.23 psf and 0.32 psf. Weights for the egg-crate are based on a unit weight of 0.20 pound per cubic foot. In addition to the weight of the cylinders and egg-crate, a weight allowance is provided for installation structure.

Insulation, Tankage—For weight-estimating purposes, it was assumed that the total external surface area of the tankage is covered with polyurethane foam having a unit weight of 0.40 psf.

Forward Interstage—The forward interstage is an aluminum semimonocoque shell used for transmitting loads between the payload and the oxygen/hydrogen stage. For weight-analysis purposes, the interstage is sized to carry axial loads at first-stage burnout, and is covered externally with an ablative coating weighing 0.15 psf.

Aft Skirt—This skirt is used to transmit loads between the forward interstage of the first stage and the tankage of the second stage. For weight-analysis purposes, the skirt is an aluminum semimonocoque shell sized to carry axial loads at first-stage burnout.

Thrust Structure—The thrust structure assumed for weights purposes is an aluminum-stiffened cone frustum that is separate from the tank structure. This stiffened cone frustum consists of a stringer-frame stiffened shell, longerons and heavy-gage shear plates (for multiengine stages only), a tension ring at the upper end of the frustum, and a compression ring at the lower end of the frustum.

Also, for engine attachment, thrust blocks and thrust-block mounting plates are provided.

Base-Heat Protection—Base-heat protection consists of an insulation blanket, weighing 0.50 psf, covering the external surface of the thrust structure and, for multiengine stages, a flame shield located slightly forward of the nozzle exit plane. The flame shield, which consists of an ablative coating over a steel sandwich base, is supported from the lower ring of the thrust structure by a trusswork of light-gage steel tubing. Typical weight allowances for the flame shield are 4 psf for a "loose" cluster of four J-2 engines, and 8 psf for a relatively "tight" cluster of three Y-1 engines.

Separation Provisions—Stages may be separated by one of several techniques (tension straps, explosive bolts, shaped charges, etc.). Design studies have indicated that the weights of stage-separation provisions are small. Typical weight allowances for a combination tension-strap/explosive-bolt concept are provided for in this study.

Propulsion System and Accessories

Engine Package (Dry)—Weight allowance for the dry J-2 engine package was 2030 pounds, and for the dry Y-1 engine package 6550 pounds. These dry weight allowances are consistent with industry data; however, it is expected that the weight of the Y-1 engine may increase approximately 20 to 40 percent during development.

Propellant-Distribution System—Pressurization equipment, fill and drain system, vent system, and propellant loading/utilization system weight allowances are based on Boeing study data for the S-2 stage and on Boeing study data developed for large oxygen/hydrogen stages. The weight allowance for the propellant-distribution system reflects an oxidizer-aft tankage configuration, the weight allowance for pressurization equipment reflects a bleed-type pressurization concept for both the fuel and oxidizer, and the weight allowance for the propellant loading/utilization system reflects an "open-loop, on-loaded fuel" concept.

Thrust-Vector-Control System—For weight-analysis purposes, it was assumed that an independent hydraulic unit is necessary for each engine for thrust-vector control. It was also assumed that the hydraulic pump will be driven from the turbopump accessory pad. (If this power source is not available, an auxiliary power unit must be employed.) Weight allowances for the thrust-vector-control system are 200 pounds per J-2 engine, and 420 pounds per Y-1 engine.

Roll-Control Provisions—Roll-control provisions are provided on the single-engine stages. These provisions consist of roll nozzles plus the plumbing required for use of the turbine exhaust gases. (If this power source is not adequate, an independent roll-control system is necessary.) Weight allowances for roll-control provisions are based on preliminary estimates only.

Staging-Rockets Group—Both ullage rockets and separation retrorockets are used on the oxygen/hydrogen stages. Ullage-rockets requirement is 0.1 g for 5 seconds; separation rockets requirement is 1.0 g for 3 seconds. Rocket weight allowances are based on the use of solid-propellant rockets having a specific impulse of 250 seconds and a mass fraction equal to 0.75. A weight allowance is also provided for attachment fittings and local support structure.

Based on the above data, the weight ratio of ullage-rocket propellant to vehicle weight at second-stage ignition is approximately 0.2 percent, and the weight ratio of separation-rocket propellant to stage weight at burnout is approximately 1.2 percent.

Because the ullage rockets are fired only during the start phase, ullage-rocket propellant weight is included under "items expended prior to ignition."

Equipment

The stage equipment consists of: control elements; telemetry system; environment-control provisions; power supply; electrical network; and range-safety/destruct systems. Control elements are the rate gyros and accelerometers, which are part of the vehicle's guidance and control system. The telemetry system consists of telemeter sets, sensors and transducers, electrical cable and wiring, and all other components required for data collection and transmission. Environment-control provisions are the structural provisions (ducting, baffles, and connectors) required for transmission of the cooling and ventilating gases to the equipment cannisters during the hold-down period. The power supply consists of batteries for providing electrical power to the thrust-vector-control system, the separation devices, the igniters on the ullage rockets and separation rockets, the telemetry system, and the range-safety/destruct systems. The electrical network includes an inverter, voltage regulator, umbilical connectors, wire, other miscellaneous components, and a raceway with thermal protection. Redundancy for range safety and destruct is provided by two identical shaped-charge explosive systems.

Weights for the items comprising stage equipment are based on a combination of past experience and study data, and are applicable to an operational stage.

Unusable-Propellant and Gas Residuals

Unusable propellant consists of the propellant trapped in the engine package(s) and the feed lines at burnout of the stage. The weight of propellant trapped in a J-2 engine package is estimated at 90 pounds,and in a Y-1 engine package 450 pounds. The weight allowance for the weight of propellant trapped in the feed lines is based on total line volumes.

Gas residuals consist only of pressurization gases. For weight-analysis purposes, a bleed-type pressurization concept was used for both the fuel and oxidizer. The weight of gaseous fuel is based on a ullage pressure of 27 psia and a mean gas temperature of 160°R at burnout. The corresponding values for the gaseous oxidizer are 31 psia and 270°R. A weight allowance is also provided for the helium-gas slugs, which are injected into the ullage volumes just prior to launch. (The purpose of the helium slugs is to raise the ullage pressures from the holddown value of 15 psia to the desired flight values of 27 and 31 psia. To prevent a pressure collapse, the injected helium gas is at the same temperature as the fuel and oxidizer.)

For the configurations of this study, the weight ratio of unusable propellant and gas residuals to main-stage propellant is approximately 0.7 percent for the stage with one J-2 engine, 0.8 percent for the stages with four J-2 engines, and 1.0 percent for the stage with three Y-1 engines.

Usable-Propellant Residuals

Usable-propellant residuals consist of a propellant utilization allowance and a reserve-propellant allowance. For stages with four or less engines (all stages in this study), the weight ratio of the propellant-utilization allowance to main-stage propellant is 1.0 percent.

The reserve propellant provides capability for a 3.5-percent variation in burnout velocity (approximately 880 fps). Based on a specific impulse of 428 seconds, the weight ratio of reserve propellant to vehicle weight at second-stage burnout is approximately 6 percent.

Items Expended Prior to Ignition

While items expended prior to ignition do not affect the mass fraction of the oxygen/hydrogen stages, they do influence first-stage performance and their weights must be taken into account. These expended items are the ullage-rocket propellant and the propellant used during the chilldown and start phase.

The ullage-rockets requirement is 0.1 g for 5 seconds. Based on this requirement and solid-propellant specific impulse of 250 seconds, the weight ratio of ullage-rocket propellant to vehicle weight at second-stage ignition is approximately 0.2 percent.

For weight purposes, the amount of propellant expended during chilldown and start of a J-2 engine is estimated at 550 pounds and for the Y-1 engine 1500 pounds.

6. SUBSYSTEMS

Subsystem requirements were extrapolated from historical data derived from Minuteman and Bomarc. With the exception of secondary power and the electrical network, growth of existing equipment in all other subsystem areas was assumed. Such items of hardware as gyros, servos, correctors, sensors and transducers, and other equipment were considered off-the-shelf items. The range-safety and destruct system was scaled from existing systems. The telemetry was considered a growth as required to provide sufficient channels to handle the necessary information.

Thus, the detailed evaluation of the general design considerations was limited to the electrical network requirements. However, a detailed schedule for major subsystems for the N-UC4 shown in Figure IVA6-1 is included for comparative purposes. The time periods were extrapolated from existing systems scaled to this particular vehicle's requirements and are representative of the development time required to integrate the various components into a reliable system.

SECONDARY POWER AND ELECTRICAL SYSTEM

Requirements

The electrical network must perform three basic functions:

1) **Power supply and distribution;**
2) **Control-signal distribution;**
3) **Monitoring signal distribution.**

All functions must be performed within the environmental and operational conditions imposed by the requirements of all the vehicles considered.

Power must be provided to three basically separate systems:

1) Vehicle subsystems and control;
2) Research and developmental system, if necessary;
3) Destruct system.

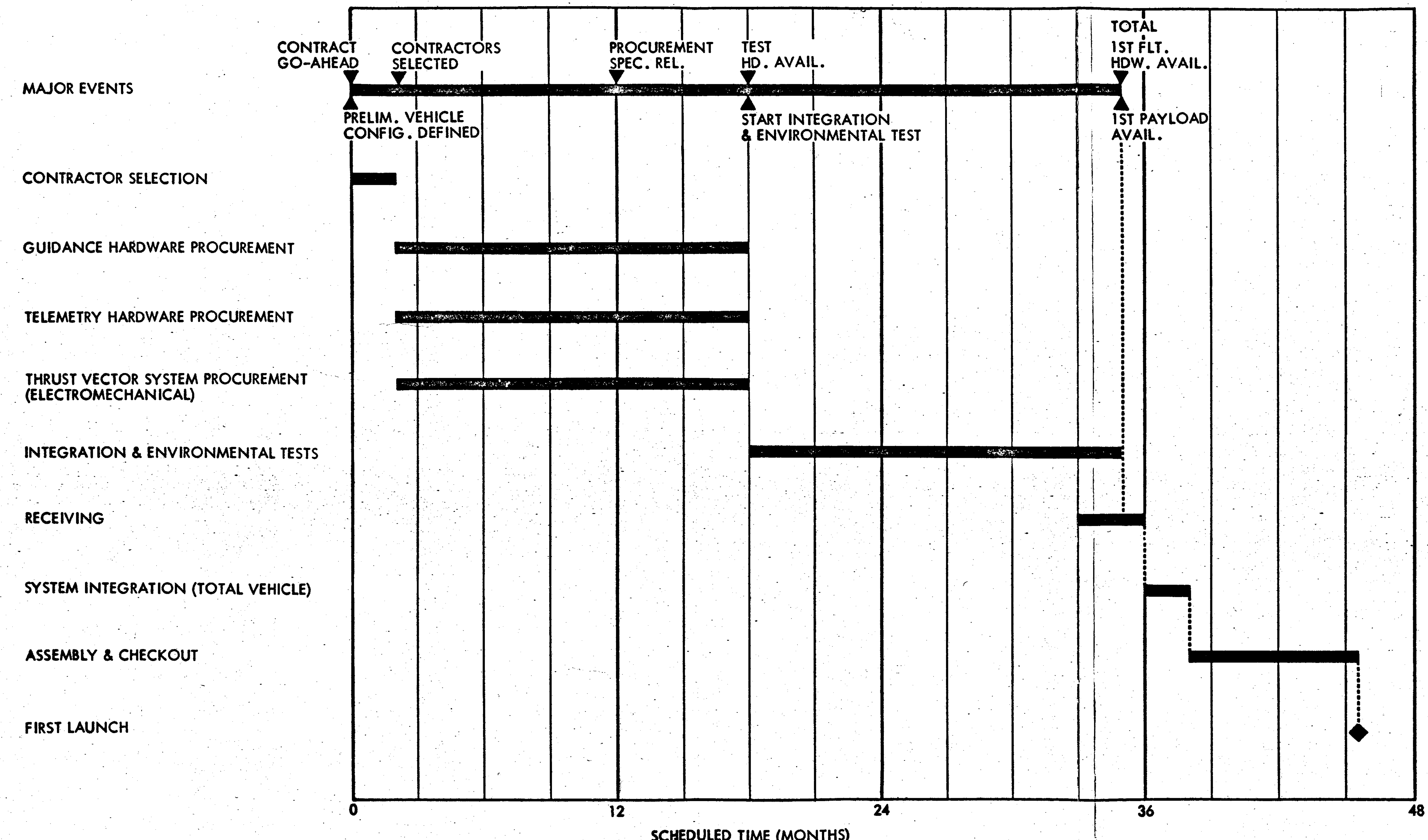


Fig. IV A6-1 ACCESSORY EQUIPMENT SCHEDULE

N-UC4

Two independent destruct systems, including power supply, must be provided. It is assumed that the individual destruct batteries are located in the forward end of each stage.

A summary of the electrical power loads imposed during flight by the respective using systems is shown in Table IVA6-1 and Figure IVA6-2. The high-voltage exploding bridgewire (EBW) provides its own conversion, and may be considered as a 28-volt direct-current load on the basic vehicle power system. All alternating-current power loads are supplied by three static inverters. The inverters provide internal voltage regulation with a 400-cps, 115-volt output. All alternating-current power loads will operate on 400-cps, 115-volt alternating-current power.

All power must be supplied from the second stage except for ground power supplied during prelaunch. During ground operations, until about 2 minutes before liftoff, all power must be provided from the ground power system through the booster umbilical. No power is required from the booster to loads outside the stage. Control-signal distribution will be required within the booster, between stages, and to the launch-control equipment. Instrumentation signals must be transmitted from the sensors to the telemetry equipment, and from the sensors to the launch-control equipment on the ground.

System Description

Figure IVA6-3 is a block diagram of the electrical network. Electrical power is derived from three 28-volt, zinc-silver oxide primary batteries, and is distributed to using equipment through teflon-insulated stranded copper conductors. Alternating-current power requirements are met through the use of three dc-ac static inverters. Each battery is activated prior to launch and provides the complete energy requirement of one of the following independent subsystems:

1) Vehicle system;
2) Research and development system;
3) Dual destruct systems.

NOTE: THE LOAD REQUIREMENTS FOR EACH VEHICLE ARE ESSENTIALLY CONSTANT.

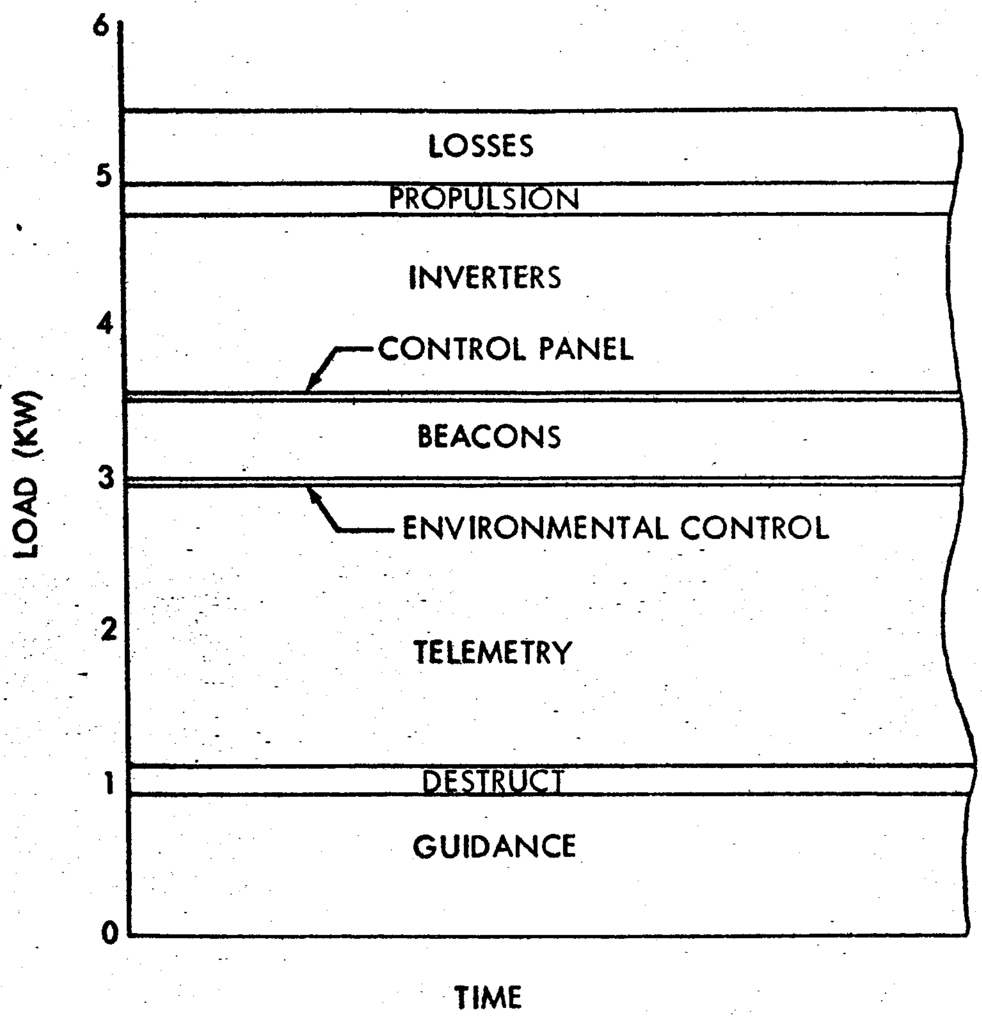


Fig. IV A6-2 LOAD PROFILE

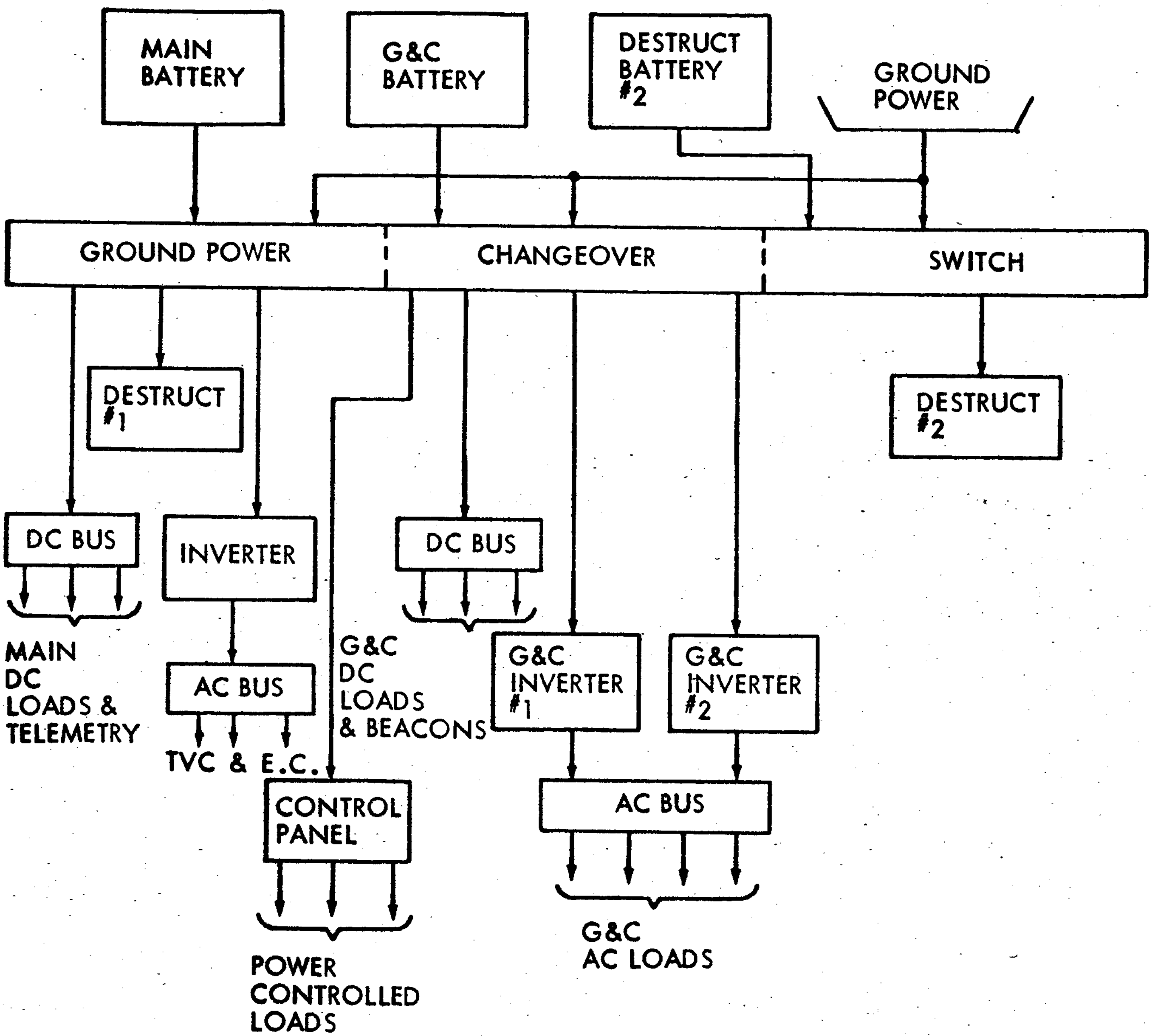


Fig. IV A6-3 ELECTRICAL SYSTEM SCHEMATIC

Table IVA6-1

ELECTRICAL POWER LOADS

GUIDANCE AND CONTROL		
Autopilot		
Control Computer		
3 Ø 400 cps 115 V		**50 watts**
28 VDC	**75 watts**	
Accelerometers and Rate Gyros		
3 Ø 400 cps 115 V		**30 watts**
Control Signal Processor		
28 VDC	**100 watts**	
Guidance System		
Autonetics Verdan		
3 Ø 400 cps 115 V		**320 watts**
ST-130 Stable Platform		
3 Ø 400 cps 115 V		**22 watts**
28 VDC	**8 watts**	
ST-130 Servoelectronics		
3 Ø 400 cps 115 V		
28 VDC	**30 watts**	
Pulse Rebalance		
3 Ø 400 cps 115 V		**102 watts**
28 VDC	**50 watts**	
Malfunction Detector		
3 Ø 400 cps 115 V		**80 watts**
Total Guidance and Control	**263 watts**	**670 watts**
PROPULSION		
Thrust-Vectoring Fluid-Injection Valves		
1 Ø 400 cps 115 V		**200 watts**

Table IVA6-1 (Cont.)

DESTRUCT			
Command Receiver (2 units)			
	28 VDC	30 watts	
Firing Unit (1 of 2 units)			
15 sec pulse	28 VDC	10 watts	
3 msec pulse	28 VDC	60 watts	
Destruct Total/Unit			
	28 VDC	85 watts	
ENVIRONMENTAL CONTROL			
30 cfm Blower w/Motor			
3 ø 400 cps	115 V		40 watts
Total Environmental Control			
3 ø 400 cps	115 V		40 watts
ELECTRICAL			
Control Panel			
	28 VDC	50 watts	
Inverters (70% eff.)			
	28 VDC	1179 watts	
Distribution Losses (10%)			
	28 VDC	485 watts	
TELEMETRY			
Measuring Racks (10 Channels/Rack)			
	28 VDC	240 watts	
SS/FM (2 Modules)			
	28 VDC	533 watts	
FM/FM (3 Modules)			
	28 VDC	800 watts	

Table IVA6-1 (Cont.)

PCM/FM (1 Module)		
	28 VDC	267 watts
Total Telemetry		
	28 VDC	1840 watts
BEACONS		
Azusa-Type/Mistram		
	28 VDC	330 watts
UDOP AN/DRN-11		
	28 VDC	85 watts
Motorola AM-2670/DRN Power Amplifier		
	28 VDC	75 watts
C Band DPN-55		
	28 VDC	30 watts
Total Beacons		
	28 VDC	520 watts

The power generation and distribution system weight is shown as a function of first-stage thrust in Figure IVA6-4.

The vehicle system includes all electrical circuitry needed for ignition of retro-rockets, valve modulation of liquid-injection thrust-vector-control media, and operation of the telemetry and data-processing systems. The network is designed to implement the above operations on command from the vehicle's guidance package. All required switching and sequencing is accomplished by timers and relays contained in the control panel.

The research and development network is isolated from the vehicle-control power network. Thus, R&D instrumentation may be removed or revised without compromising regular flight equipment. A single-point ground connection is used for both power and signal circuits and cabling is located to minimize coupling between power and signal leads. Circuitry is provided to permit monitoring of power-system performance before launch and during flight.

The electrical network and power supply described is made up of the major components listed below.

Power Supplies

Twenty-eight volt, zinc-silver oxide primary batteries are used. Primary batteries are used because of the detrimental effects of high discharge rates and salt-air environment. Silver-zinc battery weights are included in the curve shown in Figure IVA6-4. Preliminary analysis indicates that equivalent batteries of a nickel-cadmium or lead-acid type would involve an excessive weight penalty. For proper voltage regulation, battery temperatures must be maintained between 40° F and 160° F. To ensure proper environment, thermal insulation will be used as applicable.

The vehicle-power battery delivers electrical energy to the retrorocket firing unit, the static inverter, and to the control panel through which load equipment

THE FOLLOWING ITEMS ARE INCLUDED IN DISTRIBUTION SYSTEM:

3 BATTERIES
3 STATIC INVERTERS
2 PATCH PANELS
COAXIAL CABLE
SHIELDED WIRE
2 WAVE GUIDES
CLAMPS
UMBILICALS
CONNECTORS

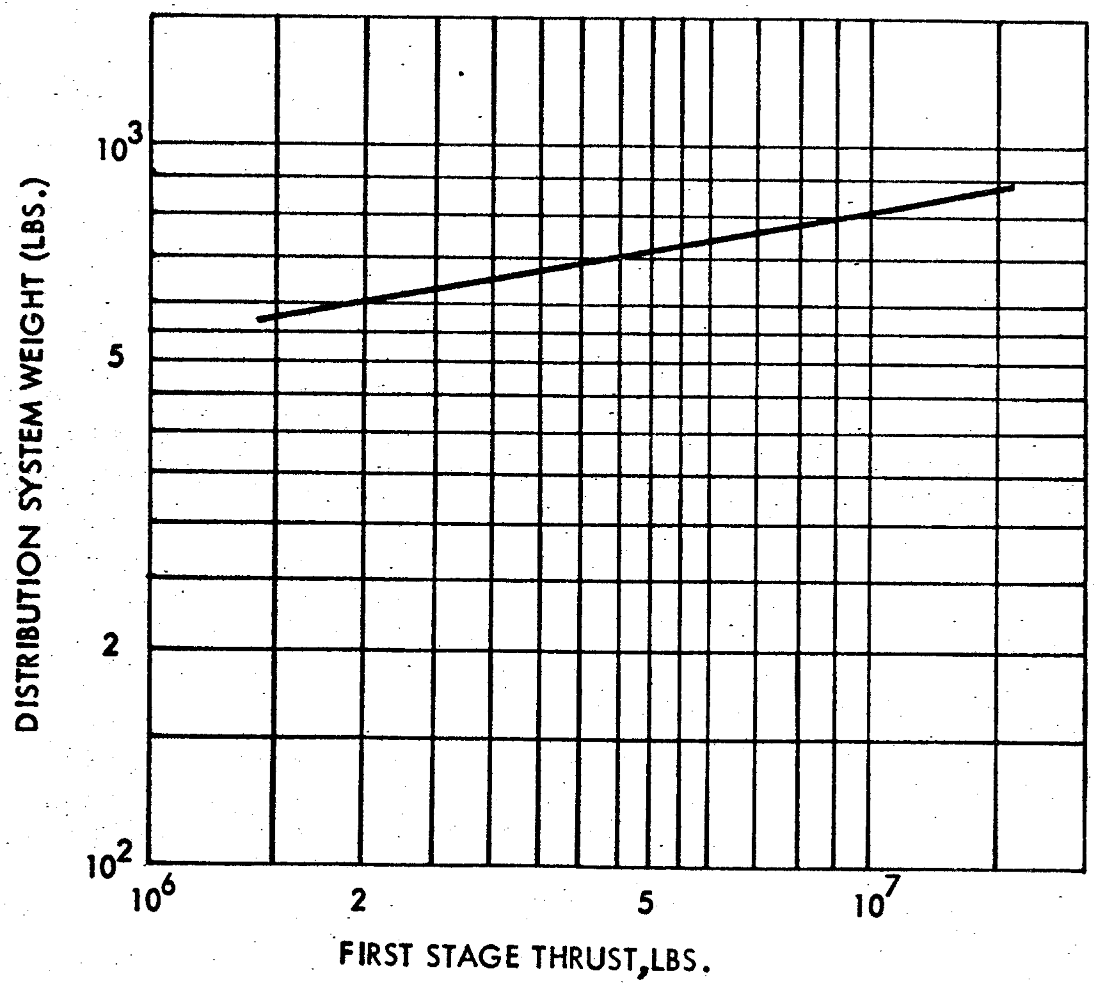


Fig. IV A6-4 FIRST STAGE THRUST VS POWER GENERATION AND DISTRIBUTION SYSTEM WEIGHT power requirements, thrust-vectoring requirements, and switching functions are furnished. Each destruct battery will deliver 30 watts to the destruct receivers continuously, with a reserve of 70 watts for demand power to the trigger unit for the duration of flight. The batteries will be activated remotely from the ground (but not connected to vehicle loads) about 30 minutes prior to liftoff to allow for voltage stabilization. The batteries are connected to vehicle loads by the power-change-over switch approximately 35 seconds before liftoff. Battery voltages are monitored during this period.

Conversion Equipment

Vehicle alternating-current power requirements are met by three 28-volt static inverters. The vehicle-power inverter provides 3-phase, 400-cycle, 115-volt power to the control instruments and the thrust-vector-control system. Each inverter has a rated output of 600 va and is conservative in design. All power inverters provide internal functions of frequency and voltage regulation.

Control Panel

With one exception, control of all in-flight functions originates from the control panel as commanded by signals received from the guidance computer. Vehicle-positioning signal inputs (the one exception) are received directly from the guidance computer. It is assumed that each command signal received from the upper stage and ground control equipment will come over a different circuit, such that addition of a command-signal program circuit to the control panel will not be necessary. The circuits needed to ground-monitor the electrical system prior to launch are also included in the control panel.

The control circuitry contains two interlocks. The power panel is interlocked with the ground control equipment to prevent arming of the stage-separation unit in the event of an inadvertent command signal. Also, the power change-over switch, which is part of the control panel, is interlocked with the ordnance destruct system and the separation unit to prevent launch until the destruct system and the separation unit are armed and the power change-over switch is in the vehicle-power position. The power change-over switch is a rotary unit.

Cabling Network

Teflon-covered, nickel-plated copper conductor is used throughout the cabling network. Minimum conductor size is AWG No. 20. All teflon insulation will be thermally protected from temperatures exceeding 550° F throughout the flight profile. Cabling routed through the engine compartment will be subjected to a high-temperature environment because of the engine-exhaust blowback. This necessitates the use of ablative materials for thermal protection in areas where the base-heat shield is not fully effective. Minuteman experience indicates that ablative materials are desirable because thermal insulation is too heavy. Teflon will be used to solve this problem. It retains some flexibility at low temperatures, will not crack, and ablates at about 1100° F.

Connector compatibility in the temperature environment is similar to the cable as a whole. Wherever possible, the connectors will be located in areas conditioned by ground equipment during standby. Connectors subjected to the extremely low temperature of liquid oxygen will have teflon inserts and seals.

The electrical umbilical connector uses isolation contacts and a dead-face front. This type of connector is used on the Minuteman, Bomarc, and other missile programs. A single-point umbilical assembly will carry all of the connections necessary for monitoring on the ground and to deliver power to run the equipment for checkout prior to launch.

To reduce radio interference and personnel hazards, the ground system provides a separate ground bus for signal circuits that is tied to the basic structure at one point only. Each stage will have its own single-point power ground and a separate instrument ground. The only point of interconnection between the power grounds and the instrumentation grounds will be in the upper stage. Each electrical sensor and item of power-utilization equipment will be grounded only to the single-point grounds provided. Each stage-ground will be connected in turn to the vehicle's single ground point. Chassis static ground, relay coil grounds, and other ground circuits not affected by noise pickup may be grounded directly to the nearest basic structure.

Wire shielding is used where necessary to reduce electrostatic pickup. Shielding is also used to reduce radiated interference emanating from wires carrying sharp pulses or transient signals. The location of shield grounds is determined by the type of interference being suppressed.

Wiring is installed so as to provide minimum coupling between circuits. The design objective on wire routing is to maintain a minimum 2-inch spacing between sensitive signal circuits and all other wiring wherever space and structure permit.

Interstaging

Two fairings will be provided on the outer surface of the vehicle to house wire and cable troughs. They will be parallel with the longitudinal axis and will be separated 180 degrees about the periphery of the vehicle. One fairing will house power wire and the other will house instrumentation wire. R&D system wire will be segregated from the regular vehicle system, thus facilitating removal of the R&D systems in the transition from the experimental vehicles to operational vehicles. One raceway can be employed for all of the cabling between booster and the upper stages.

The interstage electrical connector uses a shear-pin type release, isolation-type contacts, and a dead-face front to prevent arc-over when the two connector halves separate. Only one connector is employed to connect the booster to the upper stages. The female portion of the connector is mounted rigidly to the upper-stage structure while the male portion is mounted on the lower stage so that it is free to move in all directions. During stage separation, the male half of the interstage connector is retained by the connector yoke in the booster. Lock wires will be mounted on the connectors to prevent them from falling out of the yoke during handling. The force needed to shear the retaining pins is greater than that needed to hold the connector halves together under the expected range of vibration and shock. Torque pins are mounted in the threaded connector-coupling to prevent shearing of the retaining pins when the connector halves are mated. This type of connector has been proven through extensive testing on the Minuteman program.

Requirements established for instrumentation of the electrical network are tabulated below:

Name	Accuracy	Expected Amplitude
Battery Temperature Raceway Bundle	±5%	30° F to 180° F
Temperature Instrument Compartment	±5%	-100° F to 550° F
Wire-Bundle Temperature	±5%	0° F to 300° F
Battery Voltage	±2%	20 to 32 volts

7. FLIGHT TEST

FLIGHT TEST PHILOSOPHY

For this study it has been assumed that the liquid second stage and the payload have previously been flight tested. The test program is designed to test the solid first stage and investigate the interactions which arise from combining the vehicle.

The most difficult problem involved in planning flight test programs for the boosters under study is that of man-rating.

Criteria for man-rating are arbitrary, however, it would appear that an astronaut's career probability of survival must be greater than approximately .75 for such a career to be acceptable. Since the probability of survival of multiple missions equals the product of the probabilities of survival of the single missions, it follows that single mission survival probability must be approximately .87 if two missions are flown, .91 for three, .93 for four and so on. $\left[(P_s)^n = .75\right]$

Survival probability can be expressed as the sum of the probability of a complete successful mission and the probability of successful escape in the event of a failure, or:

$$P_{survival} = \underbrace{(R_{booster})(R_{re-entry})}_{\text{Successful missions}} + \underbrace{(1-R_{booster})R_{escape}}_{\text{Successful escapes}}$$

It can be seen that it is necessary to obtain confidence in three systems in order to man-rate an orbital system. Also, a low reliability booster system can be compensated for only by a reliable escape system.

The approach used for this study was to program tests of all three systems using the minimum number of tests which are expected to produce acceptable confidence in each system. These are:

Booster—4 successful tests

Re-entry—4 tests are available and should be made

Escape—5 tests

At the least, 9 flights, 6 of which must be successful, will be required since reentry tests can be obtained following successful completion of the boost phase and escape tests will require separate flights. Two escape tests are considered to be mandatory and are scheduled separately: escape at maximum dynamic pressure and escape at maximum first stage acceleration. Other escape tests will be obtained following booster failures.

The number of tests programed for each configuration was obtained by dividing the number of required successful tests (4 booster + 2 escape) by the predicted initial reliability, and adding, where necessary, the number required to bring the total to nine, Table IVA7-1. The median-level reliability predictions and the necessary redundancies to approach maximum stage reliabilities were used. At least nine tests are required if the initial vehicle reliability is more than .667, and more are required in the event that reliability is lower.

CONFIGURATION REQUIREMENTS

The requirement for man-rating dictated on "all-up" test configuration from the start since it is necessary to attain a high probability of escape. Also, development considerations favor early testing of upper stages. The predicted reliability growth of the configurations studied is not especially great over the test period. This indicates that with one exception any cost advantage gained by starting with dummy upper stages would be small. Two of the escape tests are planned specifically to occur during first-stage burning, and the second stages to be used for these tests need not be complete. In this case desireability of constructing suitable dummy second stages should be considered.

Because of the above considerations, the detailed costs have not been studied, however, a comparison can be made in the following manner:

The cost of a first stage test with dummy upper stages

$$C_{test} = C_{stage\ 1} + C_{dummy\ stage_2} + C_{dummy\ payload}$$

Table IVA7-1

FLIGHT TEST PROGRAM

TEST SEQUENCE		TOTAL FLIGHTS PROGRAMED 1-S1	3-SC4	3UC4	4UC4	N-UC4
1. Reduced Dynamic Pressure		1	1	1	1	1
2. Design Mission		2	2	2	2	2
3. Maximum Heating & Loads	(Proof Test)	2	2	2	2	3
4. Maximum Wind Shear	(Proof Test)	2	2	2	2	2
5. Escape at Max. Dynamic Pressure	(Proof Test)	1	1	1	1	1
6. Escape at Max. 1st stage acceleration	(Proof Test)	1	1	1	1	1
		9	9	9	9	10

7. Manned missions - telemetry for all remaining flights

Additional cost of a test with a second stage =

$$\frac{C_{stage\ 2}}{\text{Reliability Stage 1}} - C_{dummy\ payload}$$

Additional cost of a payload test assuming second stage will be tested

$$= \frac{C_{PL}}{\text{(Reliability Stage 1) (Reliability Stage 2)}}$$

FLIGHT TEST PROGRAM

The flight test programs are scheduled to proceed at the maximum rate considered reasonable in view of the need for applying test results from early flights to later flights and considering the planned processing capability. Although a capability for incorporating minor changes has been retained, no allowance has been made for major design changes. Flight test schedules for each of the configurations are shown on Figure VII-1 (Phasing Summary).

For each test program, except for the 350,000-pound payload vehicle, a smooth transition from the test launch rate into the specified operational launch rate occurs. The final launch rate in the test program for this vehicle is higher than is specified for the first operational year, but is within the estimated capacity of the facility at that time.

FLIGHT TEST OBJECTIVES

The testing described is that required to develop a booster with a solid first stage having a previously developed liquid second stage and payload. No testing has been allocated for development of the second stage and payload. These stages, however, must be tested as parts of the vehicle to determine their effect on the first stage and the effects of the first stage upon them.

A gradual approach philosophy will be used for booster and vehicle development.

The first flight will be flown on a higher trajectory than the vehicle design trajectory to reduce the effects of peak dynamic pressure, aerodynamic loads, heating, and to permit staging to take place at a lower dynamic pressure. It is, therefore, expected that a good probability of success will result on the first flight. Although the data to be obtained will not be representative of the most severe conditions to be encountered, the data will permit comparisons to be made between test data and predicted results and will highlight potential problems before flights are made to maximum conditions.

The second flight will be flown on the design trajectory and following flights will be flown to proof test critical portions of the flight regime. First-stage test objectives are listed on Figure IVA7-1 and are discussed below.

Guidance System Testing

It is assumed that the guidance system will be developed and proved before the start of the booster test program. It will still be necessary, however, to check system operation in the complete vehicle with its new environment and to tailor the response characteristics as necessary to match dynamic and control system responses.

Stage Separation Testing

Stage separation testing will be required to verify staging analyses. Measurements of engine ignition timing, thrust transients, separation rate, interstage pressures, stability and control during thrust tailoff and following separation, thrust prior to staging, uniformity of tail-off of clustered engines and effects of asymetric thrust, effectiveness of thrust reversal, and vehicle loads resulting from the staging sequence.

Loads

Structural integrity for the operating envelope will have been verified by a series of static structural tests of booster sections to determine that the structure is capable of withstanding the predicted loadings. Strain gages will be applied to structural components of the flight vehicles and calibrated prior to vehicle assembly. Data from flight tests will be compared to the predicted loads for the conditions encountered to verify that the flight loads do not exceed the design limit loads. Measurements of pressure and acoustic level will also be made. Since flight data will be obtained first under less than maximum load conditions, the maximum flight loadings can be approached with greater confidence.

Information to be obtained will include the following: Dynamic loads and frequency response, control-induced loads, engine-ignition loads, aerodynamic loads, stage-separation loads, and acoustical loads.

Heating

Information will be obtained to check aerodymanic heating, base heating, and equipment environment. Although aerodymanic heating is not expected to be severe, calorimetric and structural temperature measurements will be made to assure that undue heating does not occur. Base-heating rates and engine base temperatures will also be measured to assure that sufficient insulation has been provided in that area.

Escape System Tests

The escape system is assumed to be satisfactory for usage with the second stage prior to mating with the boosters under study. Prior to manned use, escape must be demonstrated during first-stage operation for the following: Escape at maximum dynamic pressure, escape at maximum acceleration, and escape under maximum maneuver conditions.

An escape system will be installed for each flight so that the system can be tested in the event of booster failures.

Tests of Liquid Second Stage

The second stage is considered to be developed prior to use with the solid booster. Testing with the second stage will, therefore, be limited to only that necessary to demonstrate that the interactions between the assembled components do not cause difficulty.

Testing will be required for dynamic response, structural loads, stage separation characteristics and electrical interaction, as well as testing to permit the guidance and control system to be tailored to the vehicle.

Instrumentation Performance

It will be necessary to provide a telemetry system for use during booster development and to provide data for malfunction analysis during operational use of the booster.

The telemetry system will be composed of previously developed components which will require little development in themselves. It will be necessary, however, to monitor system operation to determine that the environment does not degrade the quality of test data and that the instrumentation does not affect the operation of the flight systems.

Areas which must be investigated include the effects of the rocket engine exhaust on radio frequency transmission for telemetry, tracking, destruct, and communication systems, and the effects of flight environment on all instrumentation systems.

Propulsion

Testing of the solid first-stage motors will determine whether the flight environment causes any unwanted changes in engine operation or performance.

Information will be derived to determine igniter performance, thrust transients at ignition, specific impulse, burning rate, case insulation requirements, thrust-vector-control-operation, and thrust-tailoff characteristics.

Support Systems Testing

The development of an operational booster system must include development of suitable support systems. Procedures, handling equipment, assembly equipment and data acquisition, processing, and retrieval systems are typical of these systems.

Other Flight Test Objectives

Obtain data to evaluate and to verify proper operation of the following:

Guidance and Control

1) Trajectory sensing
2) Thrust-vector control
3) Thrust-vector commands

Payload

1) Interactions with booster
2) Escape system operation

Loads

1) Dynamic loads and frequency response
2) Control-induced loads
3) Engine-ignition loads
4) Aerodynamic loads
5) Stage-separation loads
6) Acoustical loads

Heating

1) External environment
   Structural temps

Heating rates

Base-heating rates

2) Internal equipment environment

Stage Separation

1) Sequencing
2) Control
3) Second-stage ignition
4) Stability

Instrumentation Performance

1) Telemetry system

   Antennas and RF propagation

   Transmitters

   Signal conditioners

   Transducers

   Power supplies

2) Destruct system
3) Tracking system

Propulsion

1) Specific impulse
2) Burning rate
3) Case insulation
4) Thrust vectoring
5) Ignition system

Stability and Control

1) During first-stage burning
2) First-stage tailoff

3) Second-stage coast

4) Second-stage recovery from staging

Support Systems

1) Transportation and handling equipment
2) Checkout equipment
3) Procedures
4) Data-recovery system
5) Launch equipment
6) Assembly tools and equipment
7) Range safety systems
8) Fueling equipment
9) Environmental control
10) Guidance support system
11) Quality control

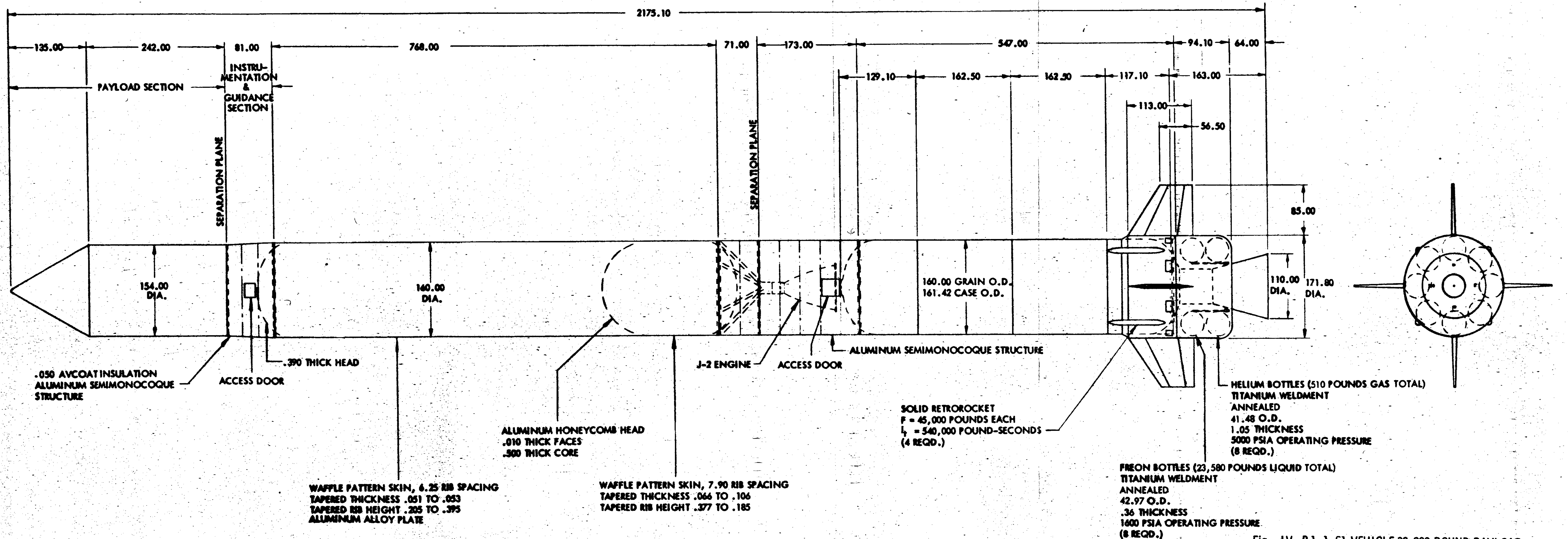


Fig. IV B1 1-S1 VEHICLE 30,000-POUND PAYLOAD

B. 30,000-POUND-PAYLOAD VEHICLE (1-S1)

1. DESCRIPTION AND ANALYSIS

GENERAL DESCRIPTION

Vehicle 1-S1 (Figure IVB-1) is a two-stage system incorporating a single segmented solid-propellant booster motor mounted in tandem with a liquid-oxygen/liquid-hydrogen powered second stage. A single J-2 engine supplies second-stage thrust. Fixed fins at the base of the booster reduce vehicle instability. Aerodynamic and base-heat protection is furnished. Secondary fluid injection is used for booster thrust-vector control.

Concept Evolution

Minimum development time was emphasized in the design of this vehicle. Concepts using clusters of two, three, and four booster motors with 120-inch grain diameters were initially considered in the design development series. The final selection of a single 160-inch grain configuration is considered a feasible means of significantly increasing stage and vehicle reliability. In addition, the chosen design possesses a geometric shape that reduces certain guidance and control problems posed by multiengine layouts.

Liquid Stage and Payload

A liquid-stage tankage diameter compatible with booster size and vehicle fineness ratio is incorporated. The payload size is that defined in the Saturn S-II work statement.

Solid-Motor Stage

The solid motor is a segmented design with two center segments. The segments were sized to facilitate transportation and handling. An internally burning case-bonded grain using a circular port with uninhibited circumferential slots at the segment joints is employed in the motor design (Figure IVA2-8). An average 84-percent cross-sectional propellant loading is utilized. Ignition is by a conventional pyrogen unit located in the head end of the booster. Silica-filled synthetic-rubber insulation is used in the end closures and over the segment joints. In these areas the insulation is tapered from a maximum at the point of initial flame exposure to zero thickness at a point equivalent to the web thickness from the initial exposure point. A synthetic-rubber liner over the entire inner chamber surface provides the case-to-grain bond. A boot located in each end segment allows for longitudinal grain shrinkage during the propellant curing cycle. (See Figure IVB-2.)

Vehicle-Control System

First-stage pitch and yaw control is supplied by the injection of helium-pressurized Freon into the exhaust stream of the fixed nozzle through four injectant ports. An auxiliary hydrogen-peroxide system at the base of the second stage provides roll control. Two sets of eight spherical pressure bottles each are used for storing the helium and Freon. This number was found to require the least space for the required capacity. Pressures are 5000 psi in the helium bottles and 1600 psi in the Freon bottles. Injector-valve actuation is by electrical signal from the guidance system. Complete mechanical and electrical redundancy is provided.

Four solid staging rockets in the vehicle's base structure are used at first-stage separation to produce a relative deceleration of the spent booster (with respect to the second stage) of 1.0 g for 3 seconds. Primacord severs the interstage connection. Ullage rockets provide 0.1-g acceleration of the second stage for 5 seconds prior to J-2 ignition.

Second-stage pitch and yaw is controlled by full gimbaling of the J-2 engine. Second-stage roll control is by the same hydrogen-peroxide system used for the first stage.

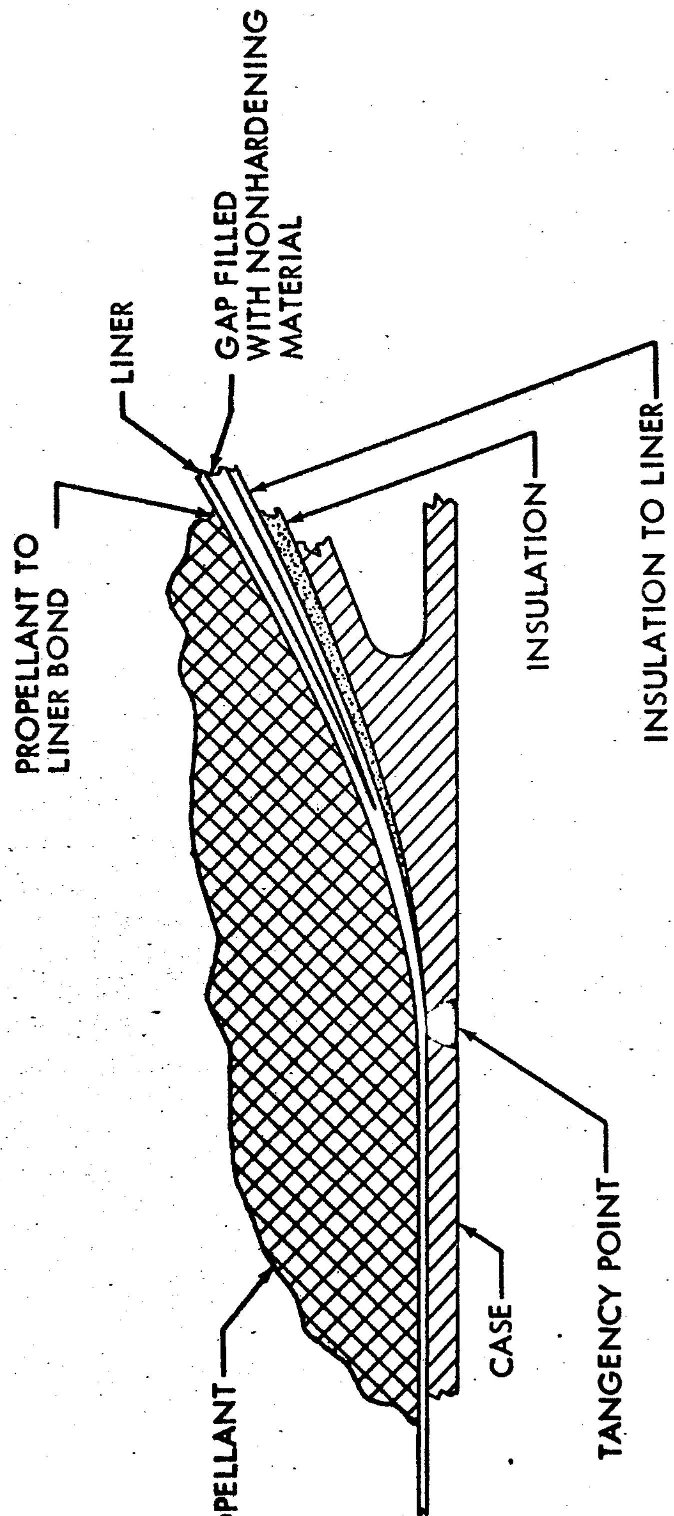


Fig. IV B-2 TYPICAL DOME END DETAIL

External Insulation

A laminated-fiberglass heat shield with a low-temperature ablative coating is incorporated for booster base-heat protection. The base of the second stage is also provided with a low-temperature ablative coating. The forward interstage is protected from aerodynamic heating by an external layer of Avcoat ablative insulation. External insulation is provided for the liquid-hydrogen pipeline.

2. PERFORMANCE

The second-stage thrust of the 30,000-pound-payload vehicle is fixed at 200,000 pounds by the use of one J-2 engine. Use of a 1.6 initial thrust-to-weight ratio for the vehicle resulted in a maximum dynamic pressure of 1110 psf and a first-stage burnout dynamic pressure of 175 psf. The initial second-stage thrust-to-weight ratio is 0.901.

The trajectory for this vehicle, including time histories of the trajectory parameters, is shown in Figure IVB-3. A velocity-altitude history for the vehicle is shown in Figure IVB-4.

3. STRUCTURAL CHARACTERISTICS OF THE 1-S1 VEHICLE

BOOSTER MOTOR CASE CONSTRUCTION

Booster motor case segments are fabricated of rolled and welded high-tensile-strength steel. The 1.4:1 semiellipsoidal segment end closures are high-strength steel assembly machined to the proper size, shape, and concentricity. Integral stub skirts are machined into the closures and cylindrical steel extensions are welded to the skirts to provide ties for the base and interstage structures. The cylindrical portions of the end segments are rolled and welded sections that are welded to the closures. The igniter and nozzle bosses and the segment end rings are machined forgings that are welded to the parent sections. The complete segment assemblies are heat-treated to 200,000-psi ultimate tensile strength.

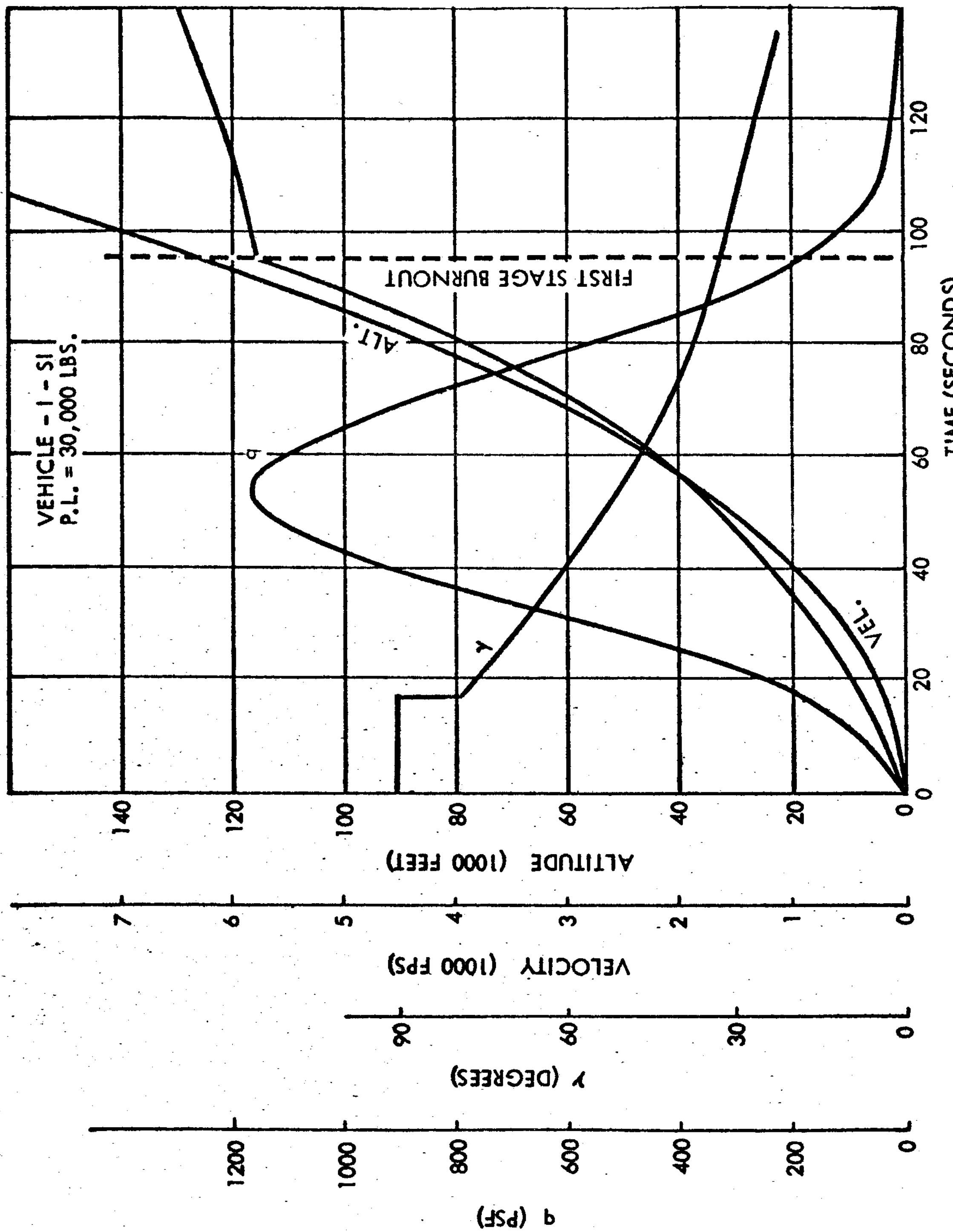


Fig. IV B-3 NASA SOLID BOOSTER STUDY VEHICLE I-SI

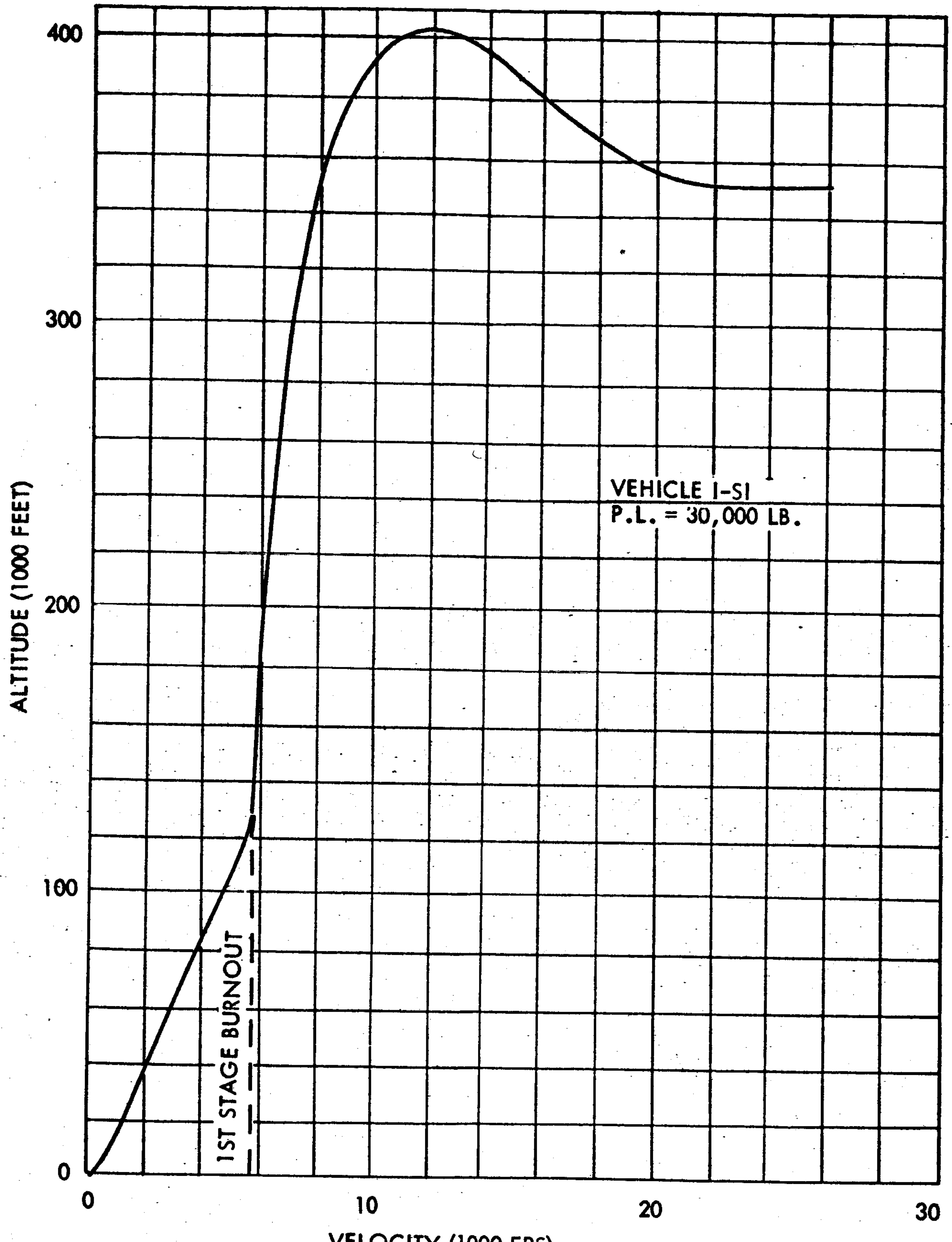


Fig. IV B-4 NASA SOLID BOOSTER STUDY
VEHICLE 1-S1

Segments are mated through the male and female end rings, which are match drilled circumferentially to receive the steel retaining pins as shown in Figure IVA3-16.

NOZZLE CONSTRUCTION

The convergent (or entrance-cap) portion of the nozzle is formed of pressure-molded silica phenolic and covered with a heavy layer of silica-filled synthetic rubber insulation. The throat section is an assembly of pressed graphite blocks backed with a monolithic section of molded silica-phenolic. The divergent portion of the nozzle (or exit cone) is of oriented silica-fiber phenolic construction. The entire assembly is encased in a steel outer shell, which receives the structural loads.

VEHICLE BASE STRUCTURE

Base structure consists of an aluminum honeycomb skin reinforced internally with circumferential frames. Two of these frames are heavy circular aluminum beams, in a plane near that of the nozzle closure, that receive the fin spars and the forged steel vehicle support pads. The secondary frames are equally spaced aluminum zee sections.

To accommodate the thrust-vectoring system storage bottles, it was necessary to increase the diameter of the base structure over that of the booster case. The adaptation is made through a circular aluminum I-beam located adjacent to the stub skirt juncture on the booster case. This member also serves as a forward fin tie-down and staging-rocket support structure. The outer skin is extended forward to the fin leading edge where it is faired into the booster case. The aluminum-alloy material used throughout the base structure is heat-treated to 70,000-psi ultimate tensile strength.

The structure aft of the vehicle support pads is divided into two halves with a hinged attachment at one side. The thrust-vector-control subsystem is assembled into this clamshell arrangement for checkout prior to vehicle assembly. In a similar manner the subassembly may be dropped for repairs or maintenance at any time without disturbing the assembled vehicle.

The Freon and helium storage bottles are forged and welded hemispherical sections of 120,000-psi ultimate-tensile-strength titanium alloy.

INTERSTAGE STRUCTURE

The aft interstage structure, located between the solid and liquid stages, consists of a corrugated aluminum-alloy skin reinforced internally with circular aluminum zee sections. A reinforced opening is provided in the skin for access to the interstage area of the assembled vehicle. A corrugated structure can be used to advantage in this application because of the simplified shape and the high length-to-diameter ratio of the interstage, which reduces the end connection penalty.

The forward interstage structure, which secures the second-stage tankage to the payload compartment, is of construction comparable to the aft interstage except that a smooth outer skin is used. Guidance, telemetry, and environment control subsystems are mounted inside this structure on a framework of aluminum tubes.

Aluminum alloy with ultimate tensile strength of 70,000 psi is used throughout the interstage structures.

SECOND-STAGE CONSTRUCTION

Liquid propellants are carried in integral tankage constructed of aluminum-alloy plate machined on the inner surface to produce waffle-pattern ribs and rolled to the proper curvature. The rib height is tapered longitudinally to provide the necessary strength at any station with minimum structural weight. End bulkheads are 1.4:1 semiellipsoids of spun aluminum construction welded to the waffle structure.

A common hemispherical bulkhead of aluminum-alloy honeycomb construction divides the tankage into two compartments, the liquid-oxygen being aft. Tank pressures are 27 psia for the hydrogen and 31 psia for the oxygen. The hydrogen pipelines bypass the compartment externally.

A conical trusswork of aluminum alloy tubes acts as support and thrust structure for the J-2 engine.

FIRST-MODE BENDING FREQUENCY

The first-mode bending frequency of the subject vehicle is 0.98 cps. Methods of increasing first-mode frequencies are discussed in Section IVA3 (Vehicle First-Mode Bending Frequencies). Also see Section IVA3 (Vehicle Structural Design) for sizing of motor cases, upper stages, fins, and TVC structural requirements.

4. PROPULSION

A single segmented solid-propellant motor with a nominal outside grain diameter of 160 inches is capable of meeting the first-stage requirements of the 1-S1 vehicle. Smaller motors were considered: two, three, or four 120-inch motors, or four 100-inch motors would be adequate; but these had adverse effects on vehicle stability and control characteristics, on stage propellant mass fraction, and on stage and vehicle reliability.

A summary description of the motor characteristics is presented in Table IVB-1, and of the motor subsystems in Table IVB-2. A 48-inch web is shown for this motor. Consultation with motor vendors later in the study indicated that a 40-inch web, with the forward intersegment faces inhibited and the aft segment radially slotted, would develop a more neutral thrust-time trace and relieve propellant stressing. Roll control could be achieved by any of several techniques including intermittant high-pressure gas discharge, monopropellant decomposition and discharge, or vectoring solid or storable-liquid auxiliary motors. As the study progressed with the other vehicles, space requirements for the helium

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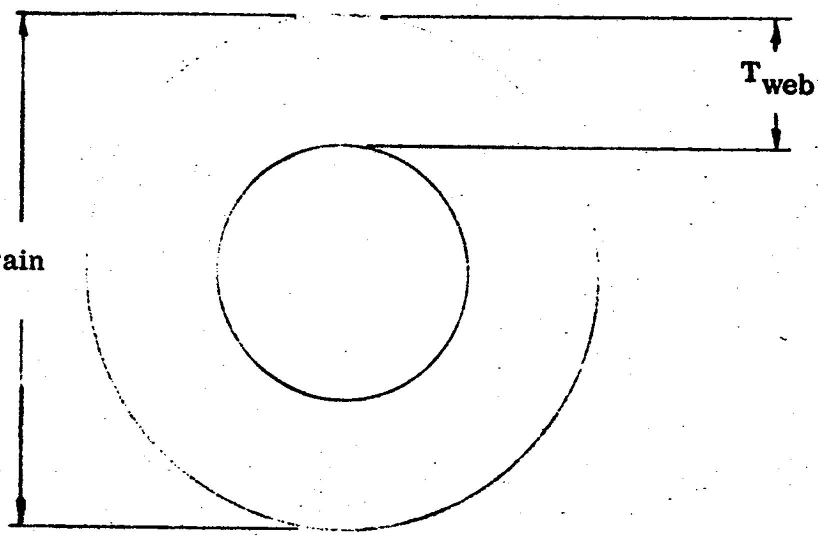
Table IVB-1

SUMMARY DESCRIPTION OF MOTOR FOR VEHICLE CONFIGURATION 1-S1



Grain Outside Diameter, inches	160
Motor Overall Length, inches	735.6
Type	Segmented
Thrust, Average During Web Burning Time, lbs.*	1,432,390
Web, Burning Time, seconds	94.44
Action Time, seconds	99.83
Action Time Impulse, lb-sec	137,251,610
Chamber Pressure, Average During Web Time, psia	800
Specific Impulse, Average During Web Time, seconds	240
Nozzle Configuration	
Expansion Ratio	8
Cant Angle, degrees	0
Motor Weight, Excluding Thrust Vector Control System, lbs	657,630
Propellant Weight per Cylindrical Segment, lbs	190,000
Total Propellant Weight Loaded, lbs	571,890
Weight of propellant remaining at end of action time, one percent per motor.	5,719
Motor Effective Mass Fraction (Wt. useful propellant/Wt. motor)	0.87
Grain Configuration	Circular Port
Cross Section Loading, percent	84
Web Fraction (Web thickness/Grain radius)	0.60
Web Thickness, inches	48
Grain Length/Outside Diameter Ratio	3.57
Grain Port/Nozzle Throat Area Ratio	2.72

* Motor performance values are given for sea level and 80°F.

Table IVB-2

MOTOR SUBSYSTEMS FOR 1-S1 VEHICLE

30,000-Pound Payload

IGNITION SYSTEM

Type: Motor-Mounted Alclo-Pyrogen

THRUST-VECTOR-CONTROL SYSTEM

Type: Freon 114B2 Injection	
Maximum Total Side Force Required, lb	34,000
Total Control Impulse Required, lb-sec	1,856,000
Maximum Total Freon Flow Rate, lb-sec	500
Total Freon Weight, lbs	21,270
Total Freon Volume, ft^3	165
Freon Pressure, psia	1,600
Cold Helium Freon Pressurization System	
Helium Weight, lbs	485
Helium Volume, ft^3	141
Helium Storage Conditions	
Pressure, psia	5,000
Temperature, deg. F	80 ± 20

ROLL CONTROL SYSTEM

Type: Hydrogen-Peroxide Intermittent Discharge	
Number of Nozzles	4
Location of Nozzles	Base of Second Stage
Thrust per Nozzles, lbs	686
System Design Total Impulse, lb-sec	274,500

DESTRUCT SYSTEM

Type: Partial-Penetration Jet Perforator pressurization system led to consideration of a monopropellant hydrazine system. If this were to be adopted in further study of the 1-S1 vehicle type, the hydrazine system would likely be assigned the roll-control function as well.

5. FLIGHT CONTROL

The first-stage configuration of this vehicle was chosen as a single module to provide the most favorable stability and control characteristics and least fin size as described in Section IVA4 (Configuration Trade Studies). A summary of stability and control requirements is presented in Table IVB-3 for this vehicle. The maximum thrust-vector angle required is 1.8 degrees and the total control-system impulse is 1.6 percent of the main-stage impulse. An auxiliary roll-control system must be provided for both stages of this vehicle since single nozzles are employed.

After the vehicle was configurated, the first-mode body-bending frequency was computed to be 0.98 cps, which is considered low for a pitch-control frequency of 0.15 cps. A lower overall fineness ratio for this vehicle would improve this spread and result in only small increases in the thrust-vector maximum deflection and control-system impulse required.

6. WEIGHTS

A summary weight statement for Vehicle 1-S1 is presented in Table IVB-4; detailed weight statements for the oxygen/hydrogen stage and the solid propellant stage are also presented in Table IVB-4. These weights are based on criteria used for weight-analysis purposes, as presented in Section IVA5. (The primary criteria used for weight-estimating purposes are summarized in Table IVA5-1 for the solid-propellant stages, and in Table IVA5-5 for the oxygen/hydrogen stages.)

Table IVB-3

STABILITY AND CONTROL CHARACTERISTICS

Vehicle 1-S1

30,000-Pound-Payload C-1 Type of Booster

	Maximum q		First-Stage	Second-Stage
	No Fins	Fins	Burnout	Startburn
Total fin size*, ft^2	0	200	200	0
$C_{N\alpha}$, per degree	0.05	0.07	0.06	0.04
C.P., fraction length aft of nose	0.35	0.51	0.40	0.35
C.G., fraction length aft of nose	0.66	0.66	0.53	0.64
q, psf	1200	1200	175	100
$M_\alpha, \frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	26.9	17.5	2.0	1.1
$M_\delta, \frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	76	76	-	6.6
M_α / M_δ	0.35	0.23	-	0.17
I, slug - $ft^2 \times 10^{-6}$	40	40	21.7	7.5
M_α / I, sec^{-2}	0.67	0.44	0.094	0.15
t_{2A}, time-to-double-amplitude, seconds	1.6	2.0	4.3	3.4
Maximum required thrust deflections				
For wind, degrees	2.1	1.40	-	
For misalignment, degrees		0.42		
Total, degrees		1.82		
Cant angle required, degrees			0	

* 4 fins of 50 ft^2 each

Table IVB-4

WEIGHT STATEMENT, VEHICLE 1-S1

Summary Weights

Payload (Includes G&C Instrumentation)	(30,000)
Second-Stage Inert Weight at Burnout	(17,960)
Dry Weight	12,020
Reserve Propellant	2,980
PU Allowance	1,740
Gas Residuals	980
Trapped Propellant	240
VEHICLE WEIGHT AT SECOND-STAGE BURNOUT	(47,960)
Second-Stage Main-stage Propellant	(173,820)
Fuel, LH_2	28,970
Oxidizer, LO_2	144,850
VEHICLE WEIGHT AT SECOND-STAGE IGNITION	(221,780)
Second-Stage Items Expended During Separation/Start	(1,000)
Propellant for Chilldown/Start	550
Ullage- Rocket Propellant	450
First-Stage Inert Weight at Burnout	(85,740)
Dry Weight	81,550
Sliver	1,430
Trapped Injectant, TVC System	2,140
Pressurant, TVC System	510
Trapped Propellant, RC System	100
Pressurant, RC System	10
VEHICLE WEIGHT AT FIRST-STAGE BURNOUT	(308,520)
First-Stage Expected Propellant Consumption	(594,330)
Solid Propellant	571,890
Injectant, TVC System	21,440
Propellant, RC System	1,000
VEHICLE WEIGHT AT LIFTOFF	(902,850)

[redacted]

Table IVB-4 (Cont.)

Detailed Weight Statement, Second Stage

Structure:	(6,940)
Tankage	3,430
Antislosh and Vortex Provisions	460
Insulation, Tank	1,180
Forward Interstage	440
Aft Skirt	860
Thrust Structure	270
Base-Heat Protection	80
Separation Provisions	90
Contingency	130
Propulsion System and Accessories:	(3,800)
Engine Package (Dry)	2,030
Propellant-Distribution System	250
Pressurization Equipment	290
Fill and Drain System	100
Vent System	70
Propellant Loading/Utilization System	70
TVC System	200
Roll-Control Provisions	50
Staging Rockets Group	580
Contingency	160
Equipment:	(1,280)
Control Elements	20
Telemetry	370
Environment-Control Provisions	.40
Power Supply and Electrical Network	680
Range-Safety and Destruct Systems	50
Contingency	120
Unusable Propellant and Gas Residuals:	(1,220)
Propellant in Engine Package	90
Propellant in Lines	130
Gaseous Hydrogen	210
Gaseous Oxygen	685
Helium Slugs	45
Contingency	60
Usable Propellant Residuals:	(4,720)
Propellant-Utilization Allowance	1,740
Reserve Propellant	2,980

[redacted]

Table IVB-4 (Cont.)

Detailed Weight Statement, Second Stage

STAGE WEIGHT AT BURNOUT	(17,960)
Mainstage Propellant:	(173,820)
STAGE WEIGHT AT IGNITION	(191,780)
Items Expended Prior to Ignition:	(1,000)
Ullage-Rocket Propellant	450
Propellant for Chilldown/Start	550
STAGE WEIGHT PRIOR TO IGNITION	(192,780)
STAGE MASS FRACTION AT IGNITION	0.9064

Detailed Weight Statement, First Stage

Basic Motor:	(64,080)
Forward Bulkhead	3,710
Cylinder	36,400
Aft Bulkhead	5,300
Nozzle	3,870
Joints, Segment-Type	6,030
Insulation and Liner, Forward Bulkhead	340
Insulation and Liner, Aft Bulkhead	1,800
Liner, Cylinder	1,000
Insulation, Segment-Type Joints	4,170
Igniter and Safe/Arm	200
Contingency	1,260
TVC System (Dry):	(10,500)
Tankage, Freon	2,330
Tankage, Helium	6,910
Controls, Plumbing, and Supports	1,260
Equipment:	(1,200)
Control Elements	20
Telemetry	280
Environment-Control Provisions	40
Power Supply and Electrical Network	570
Roll-Control System (Dry)	220
Contingency	70
Structural Provisions:	(4,250)
Forward Interstage	1,140
Aft Skirt	1,020
Fins	1,200

Table IVB-4 (Cont.)

Detailed Weight Statement, First Stage

Base-Heat Protection	430
Separation Provisions	90
Contingency	370
Separation Rockets:	(1,520)
Propellant	1,010
Rocket Inerts	340
Attachment Fittings	170
Unusable Propellant and Residuals:	(4,190)
Sliver	1,430
Freon Residual	2,140
Helium, TVC System	510
Hydrogen Peroxide Residual	100
Helium, RC System	10
STAGE WEIGHT AT BURNOUT	(85,740)
Expected Propellant Consumption:	(594,330)
Main-stage Propellant	571,890
Freon	21,440
Hydrogen Peroxide	1,000
STAGE WEIGHT AT LIFTOFF	(680,070)
STAGE MASS FRACTION AT LIFTOFF	0.8739

C. 100,000-POUND-PAYLOAD VEHICLE—SEGMENTED BOOSTER DESIGN (3-SC4)

1. DESCRIPTION AND ANALYSIS

GENERAL DESCRIPTION

Vehicle 3-SC4, shown in Figure IVC-1, is a two-stage system incorporating a cluster of four segmented solid-rocket motors mounted in tandem with a liquid-oxygen/liquid-hydrogen powered second stage. Four J-2 engines supply second-stage thrust. Fixed fins at the base of the booster stage reduce vehicle instability. Aerodynamic and base-heat protection is furnished. Secondary fluid injection is used for booster thrust-vector control.

Concept Evolution

A design ground rule used in the study specifies that the C-4 type of study vehicle be a growth version of the subject vehicle. Because of this ruling, a common number of booster motors was deemed desirable for both vehicles. Concepts using three booster motors required excessively long motors for the C-4 class of vehicle from the standpoint of internal ballistic design and vehicle fineness ratio. Four motors were subsequently chosen as the minimum feasible number for both vehicle applications.

Liquid Stage

A second design ground rule established that a Saturn S-II type of upper stage, incorporating four J-2 engines, would be used for both the C-3 and C-4 classes of vehicle. A tankage diameter was chosen for this stage that is compatible with booster sizes and vehicle fineness ratios. The payload size is that defined in the S-II work statement.

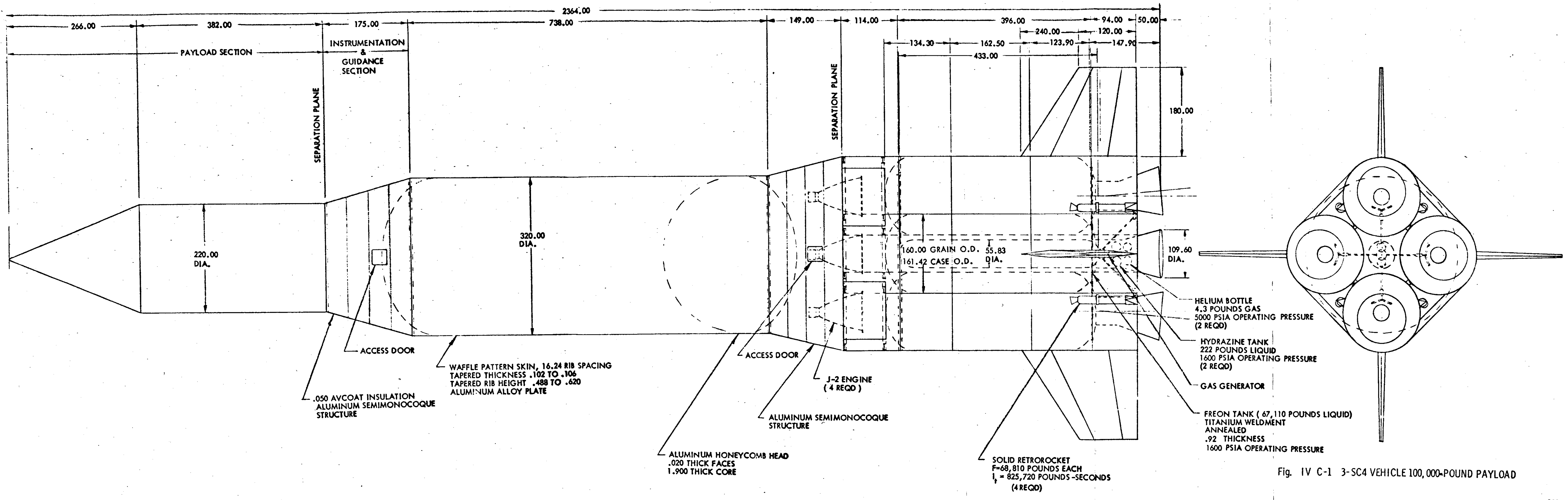


Fig. IV C-1 3-SC4 VEHICLE 100,000-POUND PAYLOAD

Solid-Motor Stage

The solid motor is of segmented design with a single center segment. An internally burning case-bonded grain using a circular port with uninhibited circumferential slots at the segment joints is employed in the booster design. (See Table IVC-1.) An 84-percent average cross-sectional propellant loading is used.

Ignition is by individual launcher-retained pyrogen units incorporating complete redundancy.

Silica-filled synthetic rubber insulation is used in the end closures and over the segment joints. In these areas the insulation is tapered from a maximum at the point of initial flame exposure to zero thickness at a point equivalent to the web thickness from the initial exposure point. A synthetic rubber liner over the entire inner chamber surface provides the case-to-grain bond. A boot, located in each end segment, allows for longitudinal grain shrinkage during the propellant-curing cycle. (See Figure IVB-2.)

Vehicle-Control System

Flight of the vehicle during booster operation is controlled by the injection of pressurized freon into the exhaust stream of the fixed nozzles. Injectant ports in the nozzle exit cones provide pitch, yaw, and roll control.

The hydrazine-gas generating system, which provides the fluid working pressure, is located between the booster nozzles and consists of a set of helium-pressurized hydrazine tanks feeding a common gas generator. This design was chosen as an alternate to grouping spherical bottles around the individual nozzles, as used on vehicle 1-S1, since the latter system imposed severe space limitations in the clustered arrangements. The limited space in the center of the cluster requires the use of a volumetrically efficient pressurization source. (See Figure IVA2-8.) A single cylindrical tank in the center of the booster-motor cluster is used to store the Freon. Gas produced by the generator is fed through a pipe to the forward end of the Freon tank, providing a back pressure to force the Freon into the tank sump and injector feed lines. The feed lines are fitted with flexible couplings to permit relative longitudinal motion of the motors. Pressures are 5000 psi in the helium bottles and 1600 psi in the hydrazine tanks, gas generator, Freon tank and feed lines. Injector-valve actuation is by electrical signal from the guidance system. Complete mechanical and electrical redundancy is provided in this area.

Four solid staging rockets in the vehicle's base structure are used during first-stage separation to produce a relative deceleration of the spent booster (with respect to the second stage) of 1.0 g for 3 seconds. Primacord severs the interstage connection. Ullage rockets provide 0.1 g acceleration of the second stage for 5 seconds prior to ignition of the J-2 engines.

Second-stage pitch, yaw, and roll are controlled by full gimbaling of the J-2 engines.

External Insulation

A laminated fiberglass heat shield with a low-temperature ablative coating is incorporated for booster base-heat protection: the base of the second stage is also provided with a low-temperature ablative coating for this purpose.

The forward interstage is protected from aerodynamic heating by an external layer of Avcoat ablative insulation.

External insulation is provided for the liquid-hydrogen pipeline.

PERFORMANCE

The second-stage thrust of the 100,000-pound-payload segmented vehicle is fixed at 800,000 pounds by the use of four J-2 engines. A 1.6 initial thrust-to-weight ratio for the vehicle resulted in a maximum dynamic pressure of 1140 psf and a dynamic pressure at first-stage burnout of 257 psf. Second-stage initial thrust-to-weight ratio is 0.935.

The trajectory chosen for this vehicle is shown in Figure IVC-2 and includes time histories of the trajectory parameters. A velocity-altitude plot for the vehicle is shown in Figure IVC-3.

STRUCTURAL CHARACTERISTICS OF THE 3-SC4 VEHICLE

Booster Motor Case Construction

The booster motor case segments are fabricated of rolled and welded high-tensile-strength steel. The 1.4:1 semiellipsoidal segment end closures are high-strength steel assembly-machined to the proper size, shape, and concentricity. Integral stub skirts are machined into the closures and cylindrical steel extensions are welded to the skirts to provide tie-ins for the base and interstage structures. The cylindrical portions of the end segments are rolled and welded sections that are welded to the closures. The closure bosses and segment end rings are machined forgings that are welded to the parent sections. The complete segment assemblies are heat-treated to 200,000-psi ultimate tensile strength.

Segments are joined by mating the male and female end rings which are match-drilled circumferentially to receive the steel retaining pins as shown in Figure IVA3-15.

Nozzle Construction

The convergent (or entrance-cap) portions of the nozzles are formed of pressure-molded silica phenolic and covered with a heavy layer of silica-filled synthetic rubber insulation. The throat sections are assemblies of pressed graphite blocks backed with monolithic sections of molded silica-phenolic. The divergent portions of the nozzles (or exit cones) are of oriented silica fiber-phenolic construction. The entire assemblies are encased in a steel outer shell which receives the structural loads.

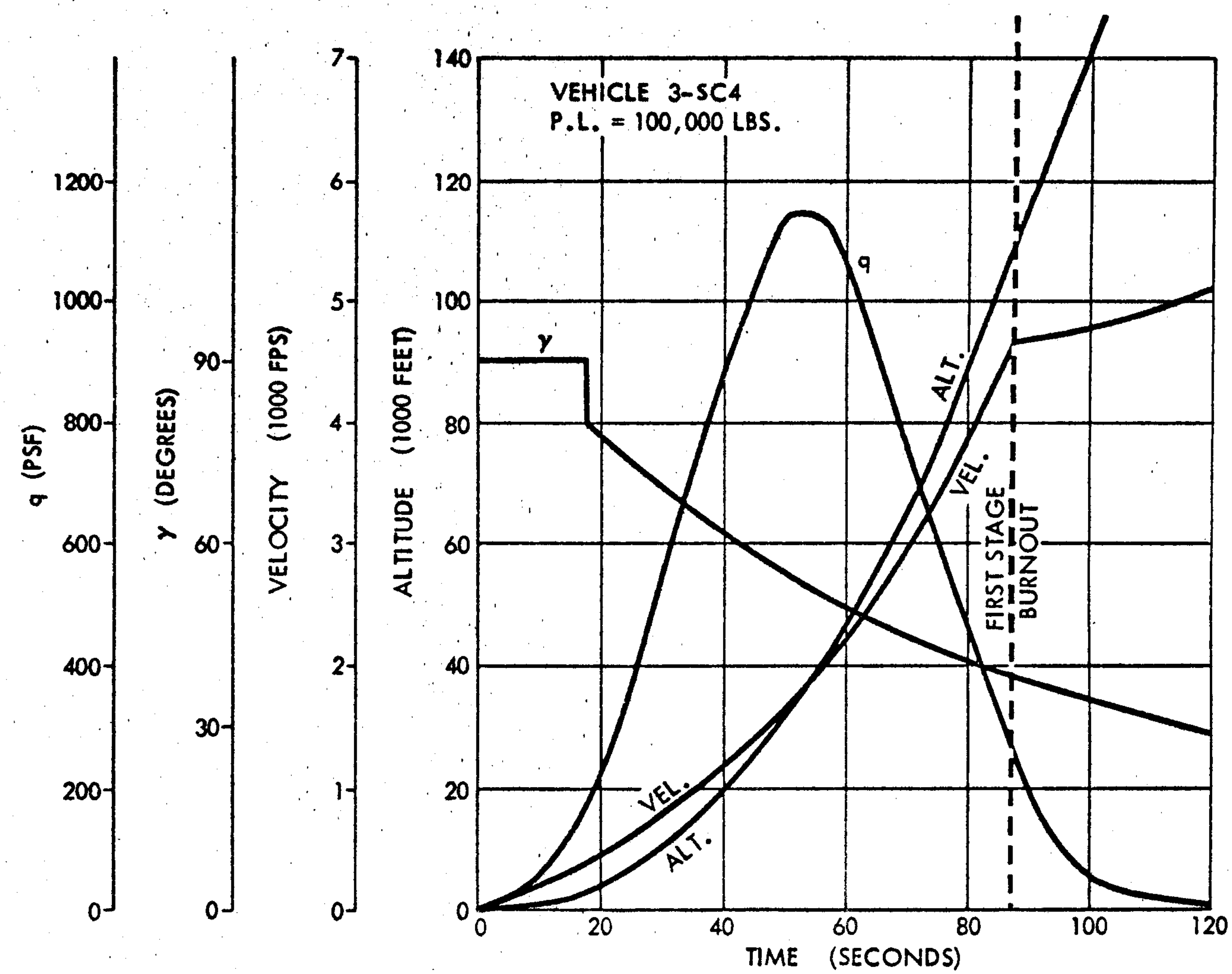


Fig. IV C-2 NASA SOLID STUDY
3-SC4

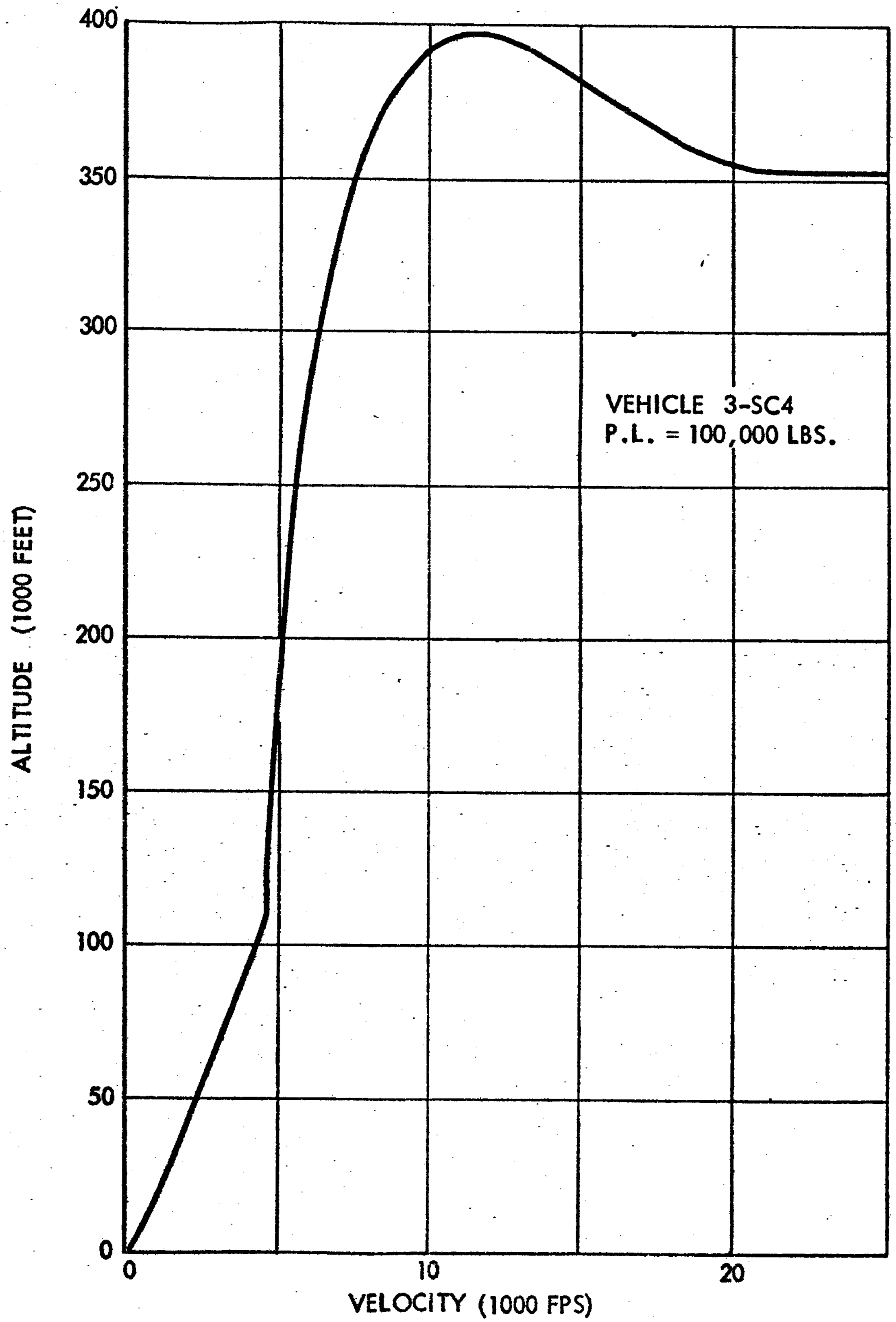


Fig. IV C-3 NASA SOLID STUDY VEHICLE 3-SC4

Vehicle Base Structure

The vehicle's launch support structure consists of four cylindrical sections of smooth aluminum-alloy skin reinforced internally with circular aluminum frames. These sections are attached to the base of the booster motors at the aft-skirt extensions. Two frames in each section are aluminum channels mounted back-to-back to receive the fin spars. The fins require attachment provisions on the motor case to react the flight torsion loads. A raised boss is required in the aft portion of each motor for this purpose. The secondary frames are equally spaced aluminum "zee" sections.

A third, channel-type frame at the base of each cylindrical section mates with the vehicle's launcher pallet. This member also serves as a staging-rocket support structure.

The aluminum-alloy material used throughout the base structure is heat-treated to 70,000-psi ultimate tensile strength.

Interstage and Intrastage Structure

The aft interstage structure, located between the solid and liquid stages, is divided into two major parts: the case extensions, or barrel sections (Figure IVA3-16); and the transition section (Figure IVA3-17).

Each barrel section consists of a smooth cylindrical outer skin of aluminum alloy reinforced at either end with a circular aluminum I-beam and stiffened with intermediate frames. The lower beam in each barrel section is attached to a corresponding skirt at the forward end of each booster motor.

Structural loads are carried from the barrel sections to the second-stage aft skirt by the interstage transition section. This structure consists of a geometrically contoured smooth aluminum outer skin reinforced internally with a series of frames and longitudinal stiffeners.

A central weldment of aluminum-alloy tubing, to which the interstage barrel sections are attached, and a beam-reinforced shear panel mounted between the outer extremities of each pair of barrel sections comprises the upper clustering structure. The clustering tie is completed by sliding-link attachments between the base structures of each motor, providing lateral restraint but permitting relative longitudinal motion of the motors.

The forward interstage structure, which secures the second-stage tankage to the payload compartment, is of comparable construction to the aft-interstage barrel sections. Vehicle guidance, telemetry, and environment-control subsystems are mounted inside this structure on a framework of aluminum-alloy tubes.

Aluminum alloy of 70,000-psi ultimate tensile strength is used throughout the interstage and intrastage structures.

A detailed structural analysis of the interstage and clustering structure is presented in Section IVA3.

<u>Second-Stage Construction</u>

The liquid propellants are carried in integral tanks constructed of aluminum-alloy plate machined on the inner surface to produce waffle-pattern ribs and rolled to the proper curvature. The rib height is tapered longitudinally to provide the necessary strength at any station with minimum structural weight. End bulkheads are 1.4:1 semiellipsoids of spun-aluminum construction welded to the waffle structure.

A common hemispherical bulkhead of aluminum-alloy honeycomb construction divides the tankage into two compartments, the liquid oxygen being located aft. Tank ullage pressures are 27 psia for the hydrogen and 31 psia for the oxygen. The hydrogen pipelines bypass the oxygen compartment externally.

A trusswork of aluminum alloy acts as support and thrust structure for the J-2 engines.

TVC Tank Mounting

The main Freon tank is suspended in the center of the clustered motor cases. The upper end is attached to the base of the cluster structure with radial supports at the lower end that allow relative expansion in the axial direction. TVC sizing requirements are given in Section IVA3.

First-Mode Bending Frequency

The first-mode bending frequency of this vehicle is approximately 1.1 cps. Methods of increasing first-mode frequencies are discussed in Section IVA3. Also see Section IVA3 for sizing of motor cases, upper stages, and fins.

PROPULSION

A cluster of four 160-inch segmented motors makes up the first stage of the 3-SC4 vehicle. Principal motor characteristics are shown in Table IVC-1, and a summary description of the motor subsystems is given in Table IVC-2.

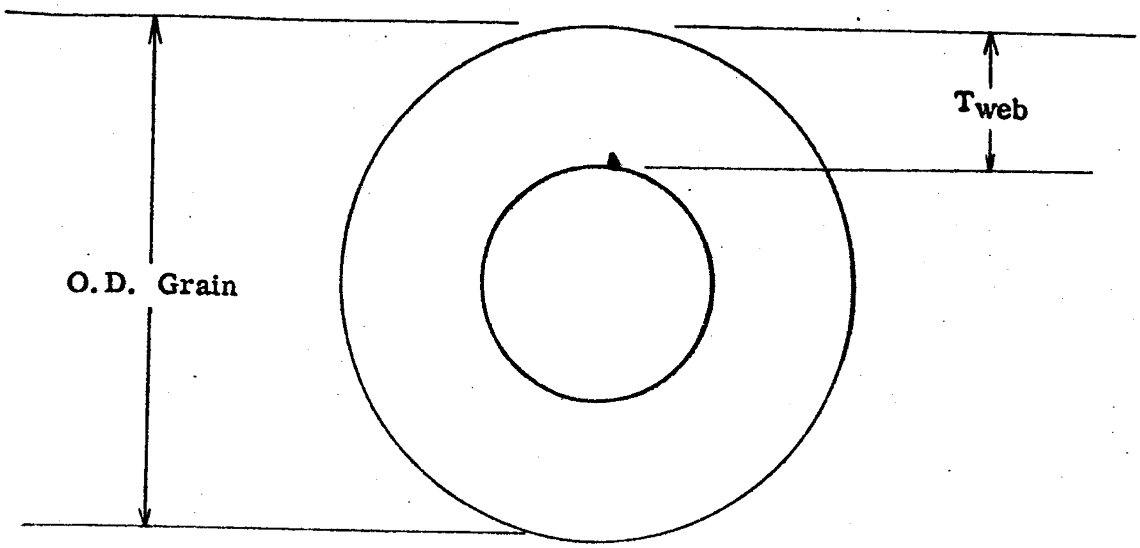
FLIGHT CONTROL

The second stage of the 100,000-pound-payload C-3 type of vehicle has nearly the same diameter as that of the first-stage cluster. Overall vehicle fineness ratio is 7.5. Stability and control characteristics for this vehicle are summarized in Table IVC-3. The maximum thrust-vector angle required is 1.7 degrees and the total control-system impulse is 1.68 percent of the main-stage total impulse.

The first-mode body-bending frequency for this vehicle is approximately 1.1 cps, which is 7.5 times the minimum pitch-control frequency. No difference is estimated between the segmented and unitized designs for this factor.

Table IVC-1

SUMMARY DESCRIPTION OF MOTOR FOR VEHICLE CONFIGURATION 3-SC4



Grain Outside Diameter, inches	160
Motor Overall Length, inches	570
Type	Segmented
Thrust, Average During Web Burning Time, lbs*	1,121,030
Web, Burning Time, seconds	85.82
Action Time, seconds	90.72
Action Time Impulse, lb/sec	97,619,290
Chamber Pressure, Average During Web Time, psia	800
Specific Impulse, Average During Web Time, seconds	240
Nozzle Configuration	
Expansion Ratio	8
Cant Angle, degrees	5
Motor Weight, Excluding Thrust-Vector-Control System, lbs	475,560
Propellant Weight per Cylindrical Segment, lbs	189,000
Total Propellant Weight Loaded, lbs	406,750
Weight of propellant remaining at end of action time, one percent per motor	4,070
Motor Effective Mass Fraction, wt. useful propellant/wt. motor	0.86
Grain Configuration	Circular Port
Cross-Section Loading, percent	84
Web Fraction (Web thickness/Grain radius)	0.50
Web Thickness, inches	48
Grain Length/Outside Diameter Ratio	2.64
Grain Port/Nozzle Throat Area Ratio	3.48

*Motor performance values are given for sea level and 80°F.

Table IVC-2

MOTOR SUBSYSTEMS FOR 3-SC4 VEHICLE

100,000-Pound Payload

IGNITION SYSTEM

Type: Launch-Retained Pyrogen

THRUST-VECTOR-CONTROL SYSTEM

Type: Freon 114B2 Injection.

Maximum Total Side Force Required, lbs	91,000
Total Control Impulse Required, lb-sec	5,900,670
Maximum Total Freon Flow Rate, lbs/sec	1,340
Total Freon Weight, lbs	67,610
Total Freon Volume, ft^3	524
Freon Pressure, psia	1,600
Hydrazine Monopropellant Freon Pressurization System	
Thermal Decomposition Chamber Length, in.	14.8
Thermal Decomposition Chamber, (L/D)	2
Total Hydrazine Weight, lbs	474
Total Hydrazine Volume, ft^3	7.5
Maximum Hydrazine Flow Rate, lbs/sec	9.40
Helium Pressure, psia	5,000
Total Helium Weight, lbs	21.9
Total Helium Volume, ft^3	6.36

DESTRUCT Jet-Perforator

Table IVC-3

STABILITY AND CONTROL CHARACTERISTICS

Vehicle 3-SC4

100,000-Pound-Payload Segmented C-3 Type Booster

	Maximum q No Fins	Maximum q Fins	First-Stage Burnout	Second-Stage Startburn
Total fin size*, ft^2	0	900	900	0
$C_{N\alpha}$, per degree	0.05	0.073	0.06	0.04
C.P., fraction length aft of nose	0.45	0.60	0.48	0.41
C.G., fraction length aft of nose	0.71	0.71	0.60	0.73
q, psf	1200	1200	257	150
M_α, $\frac{ft\text{-}lb}{rad} \times 10^{-6}$	72.8	48.9	12.0	9
M_δ, $\frac{ft\text{-}lb}{rad} \times 10^{-6}$	246	246	--	24
M_α / M_δ	0.30	0.20	--	0.37
I, slug - $ft^2 \times 10^{-6}$	112	112	71.5	29.5
M_α / I, sec^{-2}	0.65	0.44	0.17	0.31
t_{2A}, time to double amplitude, seconds	1.6	2.0	3.2	2.4
Maximum required thrust deflections				
For wind, degrees	1.8	1.20	--	--
For misalignment, degrees	--	0.52	--	--
Total, degrees	--	1.72	--	--
Cant angle required, degrees	--	--	7	--

* 4 fins of 225 ft^2 each

WEIGHTS

A summary weight statement for vehicle 3-SC4 is presented in Table IVC-4; detailed weight statements for the oxygen-hydrogen stage and the solid-propellant stage are also presented in Table IVC-4. These weights are based on criteria used for weight-analysis purposes, as presented in Section IVA4. (The primary criteria used for weight-estimating purposes are summarized in Table IVC-4 for the solid-propellant stages and in Table IVA4-5 for the oxygen/hydrogen stages.)

Table IVC-4

WEIGHT STATEMENT, VEHICLE 3-SC4

Summary Weights

Payload (includes G&C Instrumentation)	(100,000)
Second-Stage Inert Weight at Burnout	(65,520)
Dry Weight	43,230
Reserve Propellant	9,930
PU Allowance	6,900
Gas Residuals	3,940
Trapped Propellant	1,520
VEHICLE WEIGHT AT SECOND-STAGE BURNOUT	(165,520)
Second-Stage Main-Stage Propellant	(690,070)
Fuel, LH_2	115,010
Oxidizer, LO_2	575,060
VEHICLE WEIGHT AT SECOND-STAGE IGNITION	(855,590)

Second-Stage Items Expended During Separation/Start	(3,910)
Propellant for Chilldown/Start	2,200
Ullage-Rocket Propellant	1,710
First-Stage Inert Weight at Burnout	(275,250)
Dry Weight	263,620
Sliver	4,070
Trapped Injectant, TVC System	6,100
Pressurant, TVC System	1,460
VEHICLE WEIGHT AT FIRST-STAGE BURNOUT	(1,134,750)
First-Stage Expected Propellant Consumption	(1,688,000)
Solid Propellant	1,626,990
Injectant, TVC System	61,010
VEHICLE WEIGHT AT LIFTOFF	(2,822,750)

Table IVC-4 (Cont.)

Detailed Weight Statement, Second Stage

Structure:	(29,070)
Tankage	14,580
Antislosh and Vortex Provisions	1,220
Insulation, Tank	2,480
Forward Interstage	2,060
Aft Skirt	4,700
Thrust Structure	2,430
Base-Heat Protection	1,100
Separation Provisions	120
Contingency	380
Propulsion System and Accessories:	(12,490)
Engine Package (Dry)	8,120
Propellant-Distribution System	500
Pressurization Equipment	350
Fill and Drain System	140
Vent System	90
Propellant Loading/Utilization System	70
TVC System	800
Staging-Rockets Group	2,020
Contingency	400
Equipment:	(1,670)
Control Elements	20
Telemetry	640
Environment-Control Provisions	40
Power Supply and Electrical Network	775
Range-Safety and Destruct Systems	50
Contingency	145
Unusable Propellant and Gas Residuals:	(5,460)
Propellant in Engine Package	360
Propellant in Lines	1,080
Gaseous Hydrogen	840
Gaseous Oxygen	2,740
Helium Slugs	180
Contingency	260
Usable Propellant Residuals:	(16,830)
Propellant-Utilization Allowance	6,900
Reservé Propellant	9,930
STAGE WEIGHT AT BURNOUT	(65,520)
Main-Stage Propellant:	(690,070)
STAGE WEIGHT AT IGNITION	(755,590)
Items Expended Prior to Ignition:	(3,910)
Ullage-Rocket Propellant	1,710
Propellant for Chilldown/Start	2,200
STAGE WEIGHT PRIOR TO IGNITION	(759,500)
STAGE MASS FRACTION AT IGNITION	0.9133

Table IVC-4 (Cont.)

Detailed Weight Statement, First Stage

Basic Motor:	(186,660)
Forward Bulkhead	14,840
Cylinder	97,000
Aft Bulkhead	21,200
Nozzle	11,280
Joints, Segment-Type	16,080
Insulation and Liner, Forward Bulkhead	1,360
Insulation and Liner, Aft Bulkhead	6,840
Liner, Cylinder	2,680
Insulation, Segment-Type Joints	11,120
Contingency	4,260
TVC System (Dry):	(30,260)
Tankage, Freon	6,640
Tankage, Helium	19,660
Controls, Plumbing and Supports	3,960
Equipment:	(1,070)
Control Elements	20
Telemetry	390
Environment-Control Provisions	50
Power Supply and Electrical Network	550
Contingency	60
Structural Provisions:	(40,910)
Clustering Structure	18,600
Forward Interstage	5,530
Aft Skirts	4,480
Fins	6,260
Base-Heat Protection	2,280
Separation Provisions	120
Contingency	3,640
Separation Rockets:	(4,720)
Propellant	3,240
Rocket Inerts	1,080
Attachment Fittings	400
Unusable Propellant and Residuals:	(11,630)
Sliver	4,070
Freon Residual	6,100
Helium, TVC System	1,460
STAGE WEIGHT AT BURNOUT	(275,250)
Expected Propellant Consumption:	(1,688,000)
Main-Stage Propellant	1,626,990
Freon	61,010
STAGE WEIGHT AT LIFTOFF	(1,963,250)
STAGE MASS FRACTION AT LIFTOFF	0.8598

D. 100,000-POUND-PAYLOAD VEHICLE— UNITIZED BOOSTER DESIGN (3-UC4)

1. DESCRIPTION AND ANALYSIS

GENERAL DESCRIPTION

Vehicle 3-UC4, shown in Figure IVD-1, is a two-stage system incorporating a cluster of four unitized solid-rocket motors mounted in tandem with a liquid-oxygen/liquid-hydrogen powered second stage. Four J-2 engines supply second-stage thrust. Fixed fins at the base of the booster stage reduce vehicle instability. Aerodynamic and base-heat protection is furnished. Secondary fluid injection is used for booster thrust-vector control.

Concept Evolution

A design ground rule used in the study specifies that the C-4-type of study vehicle be a growth version of the subject vehicle. Because of this ruling, a common number of booster motors was deemed desirable for both vehicles. Concepts using three booster motors were found to require excessively long motors for the C-4 class vehicle from the standpoint of internal ballistic design and vehicle fineness ratio. Four motors were subsequently chosen as the minimum feasible number for both vehicle applications.

Liquid Stage and Payload

A second design ground rule established a requirement for a Saturn S-II type of upper stage incorporating four J-2 engines to be used for both the C-3 and C-4 classes of study vehicles. A tankage diameter was chosen for this stage that is compatible with booster sizes and vehicle fineness ratios. The payload size is that defined in the S-II work statement.

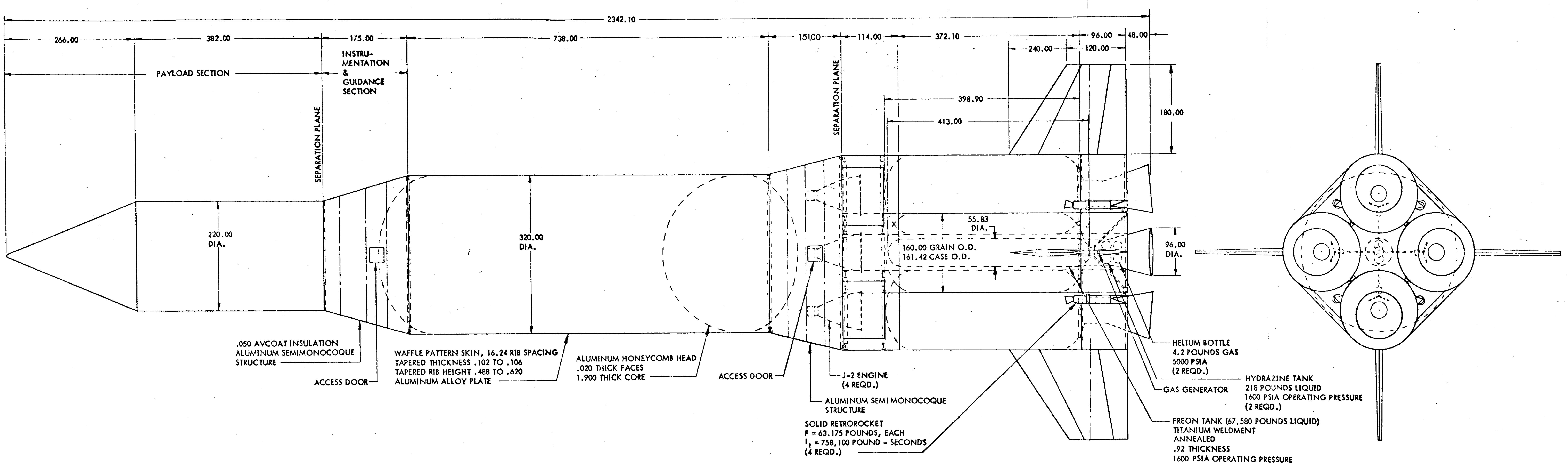


Fig. IV D-1 3-UC4 VEHICLE 100,000-POUND PAYLOAD

Solid-Motor Stage

Four 160-inch-diameter unitized solid motors are clustered for the first-stage requirements. An internally burning case-bonded grain using a five-point star perforation is employed in the motor design (see Table IVD-1). A constant port cross section is used in the forward 85 percent of the grain. The remainder of the grain incorporates a divergent taper to provide constant mass flow of gases per unit port area. An 83-percent average cross-sectional propellant loading is used.

Ignition is by individual launcher-retained pyrogen units incorporating complete redundancy.

Silica-filled synthetic-rubber insulation is used in the end closures. In these areas the insulation is tapered from a maximum at the point of initial flame exposure to zero thickness at a point equivalent to the web thickness from the initial exposure point. A synthetic-rubber liner over the entire inner chamber surface provides the case-to-grain bond. A boot, located in the dome ends, allows for longitudinal grain shrinkage during the propellant-cure cycle.

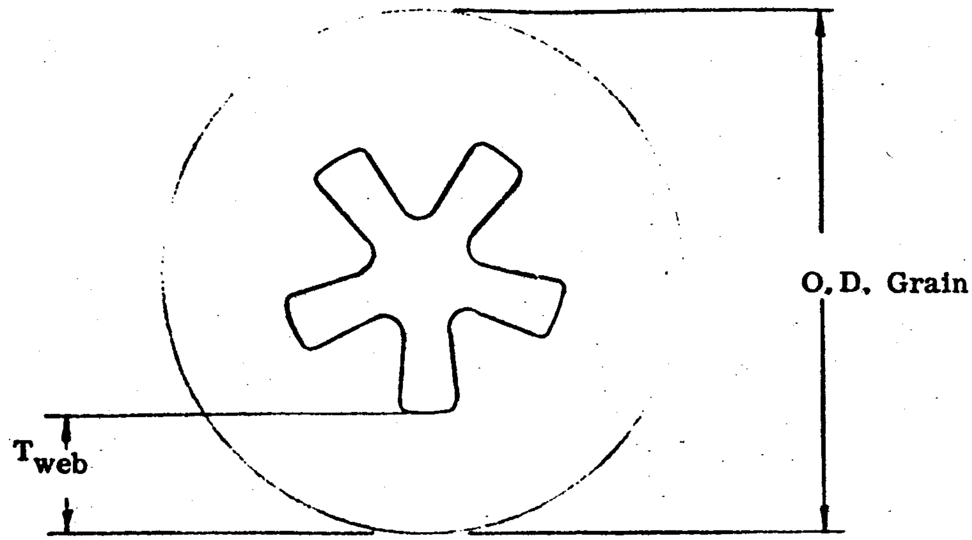
Vehicle-Control System

Flight of the vehicle during booster operation is controlled by the injection of pressurized Freon into the exhaust stream of the fixed nozzles. Injectant ports in the nozzle exit cones control pitch, yaw, and roll.

The hydrazine-gas generating system, which provides the fluid working pressure, is located between the booster nozzles and consists of a set of helium-pressurized hydrazine tanks feeding a common gas generator. This design was chosen as an alternate to grouping bottles around the individual nozzles, as used on Vehicle 1-S1, since the latter system imposes severe space limitations in the clustered arrangements. The limited space in the center of the cluster requires the use of a volumetrically efficient pressurization source (see Figure IVA2-8). A single cylindrical tank in the center of the booster-motor cluster is used to store the

Table IVD-1

SUMMARY DESCRIPTION OF MOTOR FOR VEHICLE CONFIGURATION 3-UC4



Grain Outside Diameter, inches	160
Motor Overall Length, inches	546
Type	Unitized
Thrust, Average During Web Burning Time, lbs*	1,098,720
Web Burning Time, seconds	89.05
Action Time, seconds	93.74
Action Time Impulse, lb-sec	95,676,540
Chamber Pressure, Average During Web Time, psia	800
Specific Impulse, Average During Web Time, seconds	240
Nozzle Configuration	
Expansion Ratio	8
Cant Angle, degrees	5
Motor Weight, Excluding Thrust-Vector-Control System, lbs.	461,830
Total Propellant Weight, Loaded, lbs.	398,660
Weight of propellant remaining at end of action time, one percent per motor	3,990
Motor Effective Mass Fraction, Wt. useful propellant/Wt. motor	0.87
Grain Configuration	Star Port
Cross Section Loading, percent	83
Web Fraction (web thickness/grain radius)	0.44
Web Thickness, inches	35.2
Grain Length/Outside Diameter Ratio	2.49
Grain Port/Nozzle Throat Area Ratio	3.79

*Motor performance values are given for sea level and 80°F.

Freon. Gas produced by the generator is fed through a pipe to the forward end of the Freon tank, providing a back pressure to force the Freon into the tank sump and injector feed lines. The feed lines are fitted with flexible couplings to permit relative longitudinal motion of the motors. Pressures are 5000 psi in the helium bottles and 1600 psi in the hydrazine tanks, gas generator, Freon tank, and feed lines. Injector-valve actuation is by electrical signal from the guidance system. Complete mechanical and electrical redundancy is provided in this area.

Four solid staging rockets in the vehicle's base structure are used during first-stage separation to produce a relative deceleration of the spent booster (with respect to the second stage) of 1.0 g for 3 seconds. Primacord severs the interstage connection. Ullage rockets provide 0.1 g acceleration of the second stage for 5 seconds prior to ignition of the J-2 engines.

Second-stage pitch, yaw, and roll is controlled by full gimbaling of the J-2 engines.

External Insulation

A laminated-fiberglass heat shield with a low-temperature ablative coating is incorporated for booster base-heat protection. The base of the second stage is also provided with a low-temperature ablative coating for this purpose.

The forward interstage is protected from aerodynamic heating by an external layer of Avcoat ablative insulation.

External insulation is provided for the liquid-hydrogen pipeline.

PERFORMANCE

Four J-2 engines were used in the second stage of the 100,000-pound-payload unitized vehicle, fixing the thrust at 800,000 pounds. An initial thrust-to-weight ratio of 1.6 for the vehicle resulted in a maximum dynamic pressure of 1140 psf and a dynamic pressure at first-stage burnout of 257 psf. The second-stage initial thrust-to-weight ratio is 0.935.

The trajectory parameters are shown with their time histories in Figure IVD-2. The velocity-altitude history of the trajectory is shown in Figure IVD-3.

STRUCTURAL CHARACTERISTICS OF THE 3-UC4 VEHICLE

Booster Motor Case Construction

The motor cases are fabricated from rolled and welded cylindrical sections of high-strength steel of a size compatible with existing heat-treat facilities. Forged rings of high-strength steel are welded to the ends of each section prior to heat-treat. These rings are of sufficient proportions to permit an "as welded" joint to be made between the sections after heat-treat, as shown in Figure IVA-15. Therefore, continuity of the parent metal strength is maintained.

The 1.4:1 semiellipsoidal end closures are high-strength steel assemblies machined to the proper size, shape, and concentricity. Integral stub skirts are machined into the closure and cylindrical extensions are welded to the skirts to provide tie-ins for the base and interstage structures. The closure bosses are machined forgings that are welded to the parent sections. The individual sections are heat-treated to 200,000-psi ultimate tensile strength prior to assembly.

Nozzle Construction

The convergent (or entrance-cap) portions of the nozzles are formed of pressure-molded silica-phenolic and covered with a heavy layer of silica-filled synthetic-rubber insulation. The throat sections are assemblies of pressed graphite blocks backed with monolithic sections of molded silica-phenolic. The divergent portions of the nozzles (or exit cones) are of oriented silica fiber-phenolic construction. The entire assemblies are encased in a steel outer shell, which receives the structural loads.

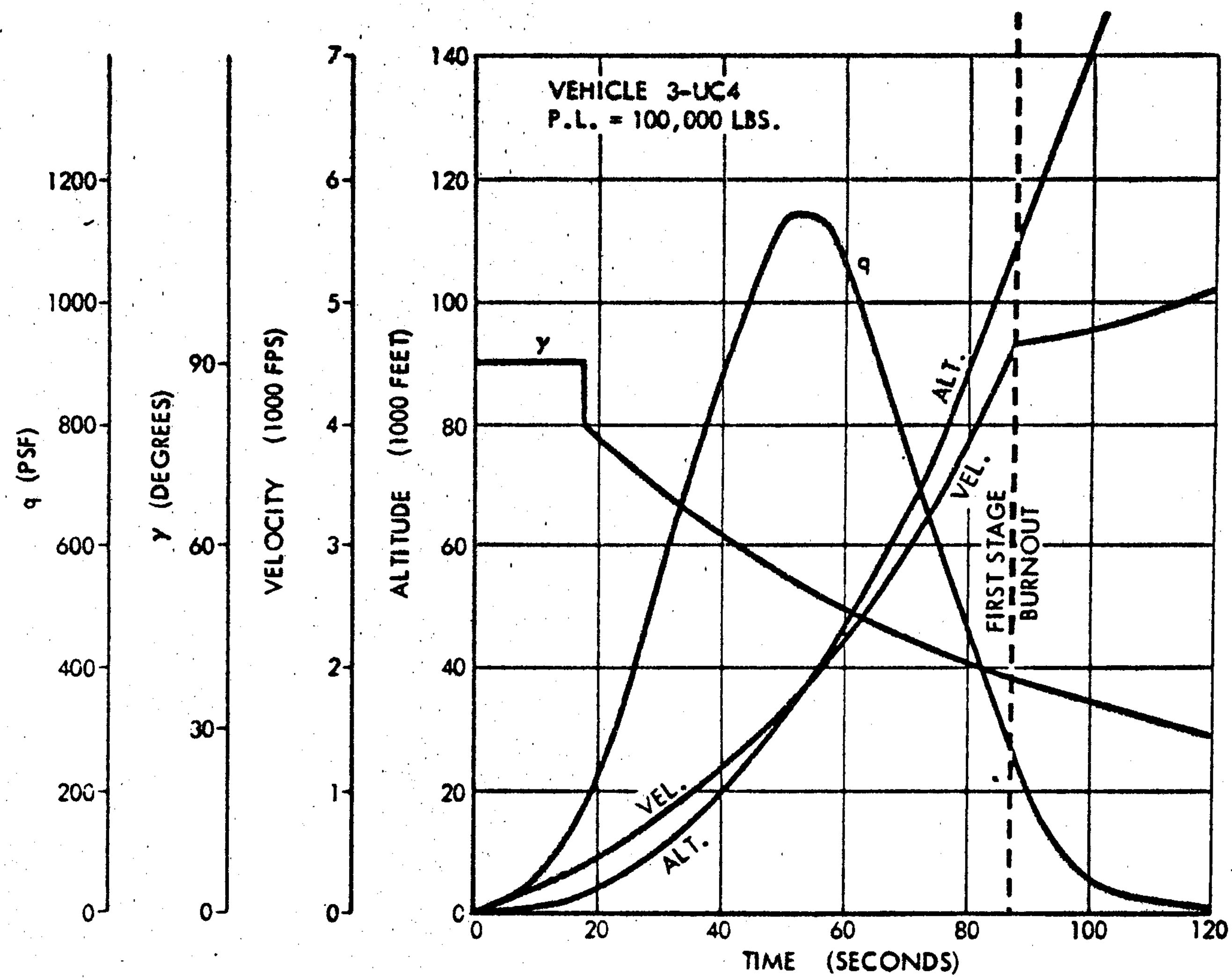


Fig. IV D-2 NASA SOLID STUDY VEHICLE 3-UC4

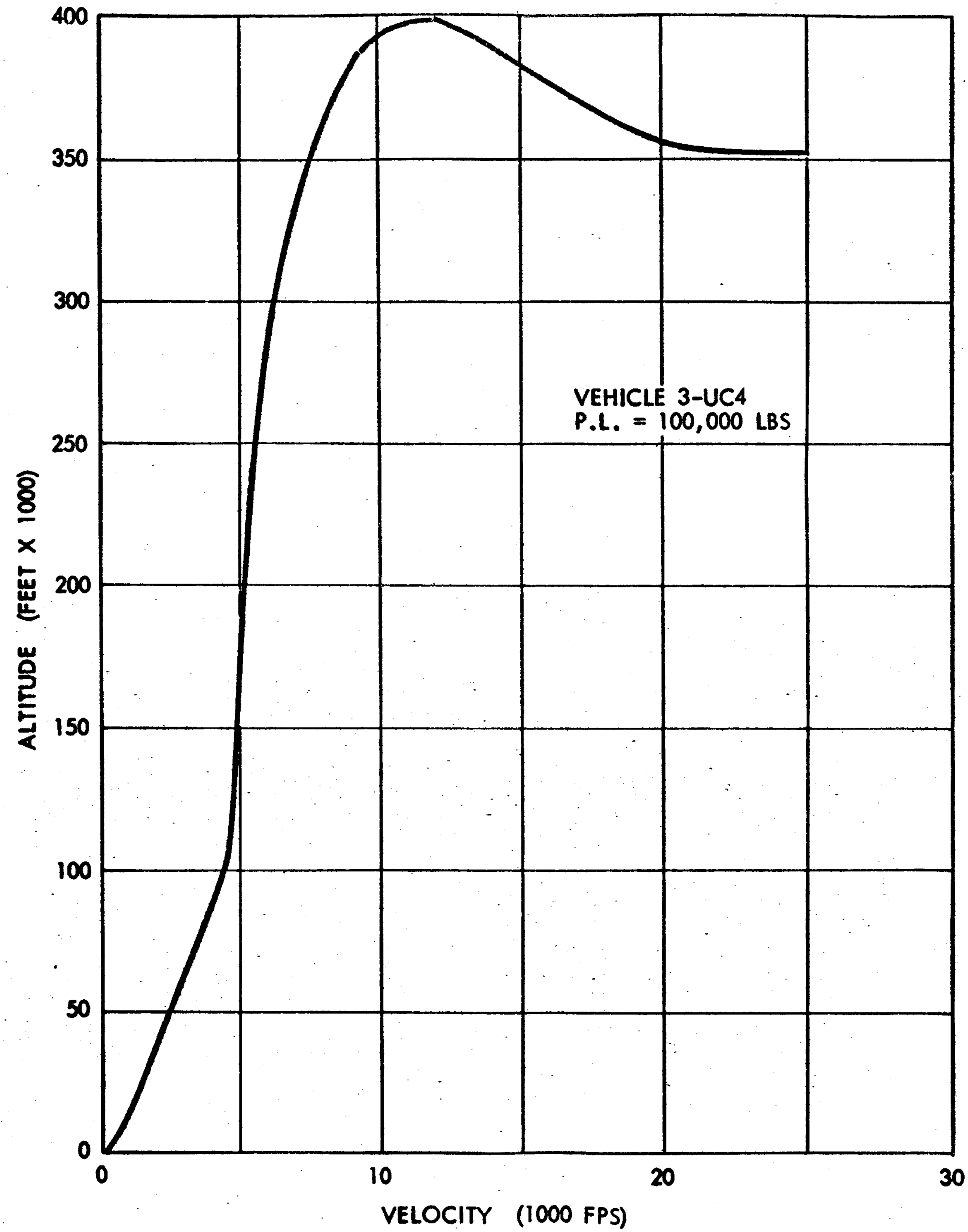


Fig. IV D-3 NASA SOLID STUDY VEHICLE 3-UC4

Vehicle Base Structure

The vehicle launch support structure consists of four cylindrical sections of smooth aluminum-alloy skin,reinforced internally with circular aluminum frames. These sections are attached to the base of the booster motors at the aft-skirt extensions. Two of the frames in each section are aluminum channels mounted back-to-back to receive the fin spars. The secondary frames are equally spaced aluminum "zee" sections. A third, channel-type frame at the base of each cylindrical section mates with the vehicle launcher pallet. This member also serves as a staging-rocket support and thrust structure. The fin leading edges are attached to the aft weld joint on the booster cases. The aluminum-alloy material used throughout the base structure is heat-treated to 70,000-psi ultimate tensile strength.

Interstage and Intrastage Structure

The aft interstage structure, located between the solid and liquid stages, is divided into two major parts: the case extensions, or barrel sections (see Figure IVA3-16); and the transition section (see Figure IVA3-17).

Each barrel section consists of a smooth cylindrical outer skin of aluminum alloy reinforced at either end with a circular aluminum I-beam and stiffened with intermediate frames. The lower beam in each barrel section is attached to a corresponding skirt at the forward end of each booster motor.

Structural loads are carried from the barrel sections to the second-stage aft skirt by the interstage transition section. This structure consists of a geometrically contoured smooth aluminum outer skin reinforced internally with a series of frames and longitudinal stiffeners.

A central weldment of aluminum-alloy tubing to which the interstage barrel sections are attached, and a beam-reinforced shear panel mounted between the outer extremities of each pair of barrel sections comprises the upper clustering structure. The clustering tie is completed by sliding-link attachments between the base structures of each motor, providing lateral restraint but permitting relative longitudinal motion of the motors.

The forward interstage structure, which secures the second-stage tankage to the payload compartments, is of comparable construction to the aft interstage barrel sections. Vehicle guidance, telemetry, and environment control subsystems are mounted inside this structure on a framework of aluminum--alloy tubes.

Aluminum alloy with ultimate tensile strength of 70,000 psi is used throughout the interstage and intrastage structures.

Second-Stage Construction

The liquid propellants are carried in integral tankage constructed of aluminum-alloy plate machined on the inner surface to produce waffle-pattern ribs and rolled to the proper curvature. The rib height is tapered longitudinally to provide the necessary strength at any station with minimum structural weight. End bulkheads are 1.4:1 semiellipsoids of spun-aluminum construction welded to the waffle structure.

A common bulkhead of aluminum-alloy honeycomb comstruction divides the tankage into two compartments, the liquid-oxygen being aft. Tank ullage pressures are 27 psia for the hydrogen and 31 psia for the oxygen. The hydrogen pipelines bypass the oxygen compartment externally.

A trusswork of aluminum tubes acts as support and thrust structure for the J-2 engines.

Base Heating

The base-heating problem requires a heat shield mounted between four motor skirts, which may move relative to one another. Section IVA3 defines the relative movement between motors. The solution to this problem will require development work. A possible solution may be a ductile metal or glass laminate coated with a silastic-type insulator.

TVC Tank Mounting

The main Freon tank is suspended in the center of the clustered motor cases. The upper end is attached to the base of the cluster structure, with radial supports at the lower end that allow relative expansion in the axial direction. TVC sizing requirements are given in Section IVA3.

Upper-Skirt Insulation

Heating requirements for aluminum forward skirts were established in the Phase I investigation. Based on these values, an estimate of required thermal protection was obtained. An 0.05 thickness of Avcoat ablative insulator is recommended.

First-Mode Bending Frequency

The first-mode bending frequency of this vehicle was approximately 1.2 cps. Methods of increasing first-mode frequencies are discussed in Section IVA3.

PROPULSION

The 3-UC4 vehicle's first stage consists of a cluster of four unitized 160-inch motors. The motors are described in Table IVD-1, and sybsystem characteristics are given in Table IVD-2.

The grain design is adapted from one developed by Thiokol Chemical Corp. for a 240-inch motor. Scaling it to the present diameter results in a core configuration relatively conservative with respect to grain stresses and propellant-burning-rate requirements. Some compromise in motor volumetric loading is involved, compared to other suggested designs. A typical calculated thrust-time trace for this motor is shown in Figure IVD-4. This grain cross-section was adopted as the reference design for all the unitized motors of this study.

Table IVD-2

MOTOR SUBSYSTEMS FOR 3-UC4 VEHICLE

100,000-Pound Payload

IGNITION SYSTEM

Type: Launch-Retained Pyrogen

THRUST-VECTOR-CONTROL SYSTEM

Type: Freon 114B2 Injection	
Maximum Total Side Force Required, lbs	91,000
Total Control Impulse Required, lb-sec	5,783,300
Maximum Total Freon Flow Rate, lbs/sec	1,340
Total Freon Weight, lbs	66,270
Total Freon Volume, ft^3	514
Freon Pressure, psia	1,600
Hydrazine Monopropellant Freon Pressurization System	
Thermal Decomposition Chamber Length, inches	14.8
Thermal Decomposition Chamber, (L/D)	2
Total Hydrazine Weight, lbs	465
Total Hydrazine Volume, ft^3	7.4
Maximum Hydrazine Flow Rate, lbs/sec	9.40
Helium Pressure, psia	5,000
Total Helium Weight, lbs	21.5
Total Helium Volume, ft^3	6.23

DESTRUCT Jet-Perforator

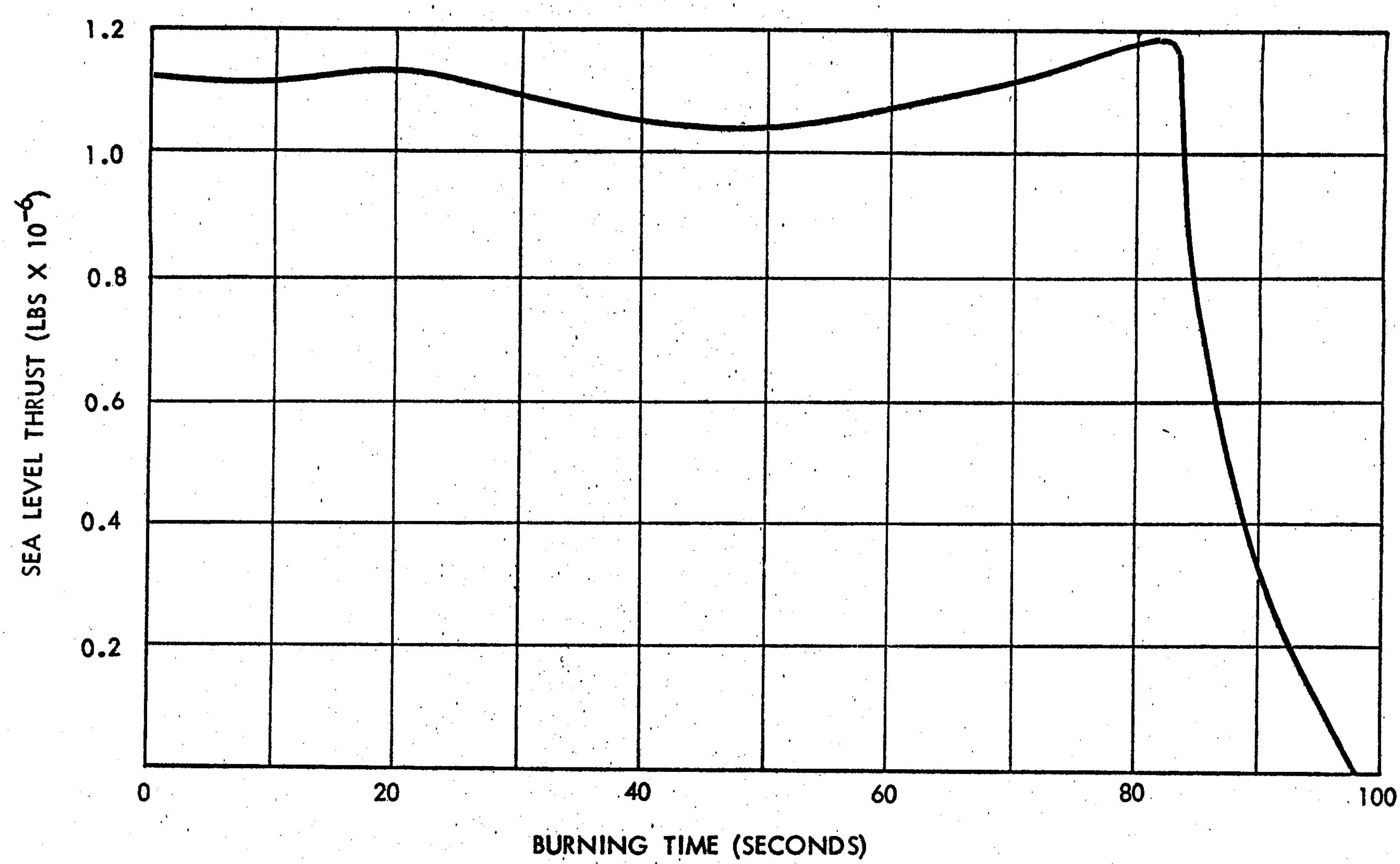


Fig. IV D-4 TYPICAL THRUST-TIME CHARACTERISTIC FOR 160-INCH UNITIZED MOTOR

FLIGHT CONTROL

The second stage of the 100,000-pound-payload C-3 type of vehicle has nearly the same diameter as that of the first-stage cluster. Overall vehicle fineness ratio is 7.5. A summary of the stability and control characteristics for this vehicle is presented in Table IVD-3. The maximum thrust-vector angle required is 1.7 degrees and the total control-system impulse is 1.68 percent of the mainstage impulse.

The first-mode body-bending frequency for this vehicle is approximately 1.1 cps, which is 7.5 times the minimum pitch-control frequency. No difference is estimated between the segmented and unitized designs for this factor.

WEIGHTS

A summary weight statement for Vehicle 3-UC4 is presented in Table IVD-4; detailed weight statements for the oxygen/hydrogen stage and the solid-propellant stage are also presented in Table IVD-4. These weights are based on criteria used for weight-analysis purposes, as presented in Section IVA-4. (The primary criteria used for weight-estimating purposes are summarized in Table IVA4-1 for the solid-propellant stages and in Table IVA4-5 for the oxygen/hydrogen stages.)

Table IVD-3

STABILITY AND CONTROL CHARACTERISTICS

VEHICLE 3-UC4

100,000-Pound-Payload Unitized C-3 Type of Booster

	MAXIMUM q NO FINS	MAXIMUM q FINS	FIRST-STAGE BURNOUT	SECOND-STAGE STARTBURN
Total fin size*, ft^2	0	900	900	0
$C_{N\alpha}$, per degree	0.05	0.073	0.06	0.04
C.P., fraction length aft of nose	0.45	0.60	0.48	0.41
C.G., fraction length aft of nose	0.71	0.71	0.60	0.73
q, psf	1200	1200	257	150
$M_\alpha, \frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	72.8	48.9	12.0	9
$M_\delta, \frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	246	246	-	24
M_α/M_δ	0.30	0.20	-	0.37
I, slug - ft^2 x 10^{-6}	112	112	71.5	29.5
$M_{\alpha/I}$, sec^{-2}	0.65	0.44	0.17	0.31
t_{2A}, time to double amplitude, seconds	1.6	2.0	3.2	2.4
Maximum required thrust deflections				
For wind, degrees	1.8	1.20	-	
For misalignment, degrees		0.52		
Total, degrees		1.72		
Cant angle required, degrees			7	

* 4 fins of 225 ft^2 each

Table IVD-4

Weight Statement, Vehicle 3-UC4

Summary Weights

Payload (includes G&C Instrumentation)	(100,000)
Second-Stage Inert Weight at Burnout	(65,520)
Dry Weight	43,230
Reserve Propellant	9,930
PU Allowance	6,900
Gas Residuals	3,940
Trapped Propellant	1,520
VEHICLE WEIGHT AT SECOND-STAGE BURNOUT	(165,520)
Second-Stage Main-stage Propellant	(690,070)
Fuel, LH_2	115,010
Oxidizer, LO_2	575,060
VEHICLE WEIGHT AT SECOND-STAGE IGNITION	(855,590)
Second-Stage Items Expended During Separation/Start	(3,910)
Propellant for Chilldown/Start	2,200
Ullage-Rocket Propellant	1,710
First-Stage Inert Weight at Burnout	(252,690)
Dry Weight	229,330
Sliver	15,950
Trapped Injectant, TVC System	5,980
Pressurant, TVC System	1,430
VEHICLE WEIGHT AT FIRST-STAGE BURNOUT	(1,112,190)
First-Stage Expected Propellant Consumption	(1,654,430)
Solid Propellant	1,594,630
Injectant, TVC System	59,800
VEHICLE WEIGHT AT LIFTOFF	(2,766,620)

Table IVD-4 (Cont.)

Detailed Weight Statement, Second Stage

Structure:	(29,070)
Tankage	14,580
Antislosh and Vortex Provisions	1,220
Insulation, Tank	2,480
Forward Interstage	2,060
Aft Skirt	4,700
Thrust Structure	2,430
Base-Heat Protection	1,100
Separation Provisions	120
Contingency	380
Propulsion System and Accessories:	(12,490)
Engine Package (Dry)	8,120
Propellant-Distribution System	500
Pressurization Equipment	350
Fill and Drain System	140
Vent System	90
Propellant Loading/Utilization System	70
TVC System	800
Staging-Rockets Group	2,020
Contingency	400
Equipment:	(1,670)
Control Elements	20
Telemetry	640
Environment-Control Provisions	40
Power Supply and Electrical Network	775
Range-Safety and Destruct Systems	50
Contingency	145
Unusable Propellant and Gas Residuals:	(5,460)
Propellant in Engine Package	360
Propellant in Lines	1,080
Gaseous Hydrogen	840
Gaseous Oxygen	2,740
Helium Slugs	180
Contingency	260
Usable Propellant Residuals:	(16,830)
Propellant-Utilization Allowance	6,900
Reserve Propellant	9,930
STAGE WEIGHT AT BURNOUT	(65,520)
Main-stage Propellant:	(690,070)
STAGE WEIGHT AT IGNITION	(755,590)

Table IVD-4 (Cont.)

Detailed Weight Statement, Second Stage

Items Expended Prior to Ignition:	(3,910)
Ullage-Rocket Propellant	1,710
Propellant for Chilldown/Start	2,200
STAGE WEIGHT PRIOR TO IGNITION	(759,500)
STAGE MASS FRACTION AT IGNITION	0.9133

Detailed Weight Statement, First Stage

Basic Motor:	(153,360)
Forward Bulkhead	14,840
Cylinder	92,060
Aft Bulkhead	21,200
Nozzle	10,900
Insulation and Liner, Forward Bulkhead	1,360
Insulation and Liner, Aft Bulkhead	6,840
Liner, Cylinder	2,580
Contingency	3,580
TVC System (Dry):	(29,640)
Tankage Freon	6,520
Tankage, Helium	19,180
Controls, Plumbing, and Supports	3,940
Equipment:	(1,070)
Control Elements	20
Telemetry	390
Environment-Control Provisions	50
Power Supply and Electrical Network	550
Contingency	60
Structural Provisions:	(40,910)
Clustering Structure	18,600
Forward Interstage	5,530
Aft Skirts	4,480
Fins	6,260
Base-Heat Protection	2,280
Separation Provisions	120
Contingency	3,640
Separation Rockets:	(4,350)
Propellant	2,980
Rocket Inerts	990

Table IVD-4 (Cont.)

Detailed Weight Statement, First Stage

Attachment Fittings	380
Unusable Propellant and Residuals:	(23,360)
Sliver	15,950
Freon Residual	5,980
Helium, TVC System	1,430
STAGE WEIGHT AT BURNOUT	(252,690)
Expected Propellant Consumption	(1,654,430)
Main-stage Propellant	1,594,630
Freon	59,800
STAGE WEIGHT AT LIFTOFF	(1,907,120)
STAGE MASS FRACTION AT LIFTOFF	0.8675

E. 180,000-POUND-PAYLOAD VEHICLE—TANDEM DESIGN (4-UC4)

1. DESCRIPTION AND ANALYSIS

GENERAL DESCRIPTION

Vehicle 4-UC4, shown in Figure IVE-1, is a two-stage system incorporating a cluster of four unitized solid rocket motors mounted in tandem with a liquid-oxygen/liquid-hydrogen powered second stage. Four J-2 engines supply second-stage thrust. Fixed fins at the base of the booster stage reduce vehicle instability. Aerodynamic and base-heat protection is furnished. Secondary fluid injection is used for booster thrust-vector control.

Concept Evolution

A design ground rule used in the study specifies that the subject vehicle be a growth version of the C-3 type of study vehicle. Because of this ruling, a common number of booster motors was deemed desirable for both vehicles. Concepts using three booster motors were found to require excessively long motors for the subject vehicle from the standpoint of internal ballistic design and vehicle fineness ratio. Four motors were subsequently chosen as the minimum feasible number for both vehicle applications.

Liquid Stage and Payload

A second design ground rule established a requirement for a Saturn S-II type of upper stage incorporating four J-2 engines to be used for both the C-3 and C-4 classes of study vehicles. A tankage diameter was chosen for this stage that is compatible with booster sizes and vehicle fineness ratios.

The payload size is that defined in the S-II work statement, with the additional payload considered to be propellants. Assuming an average density of 400 pounds per inch of length, the length of the cylindrical section of the payload is increased 200 inches over that of the C-3 type vehicle.

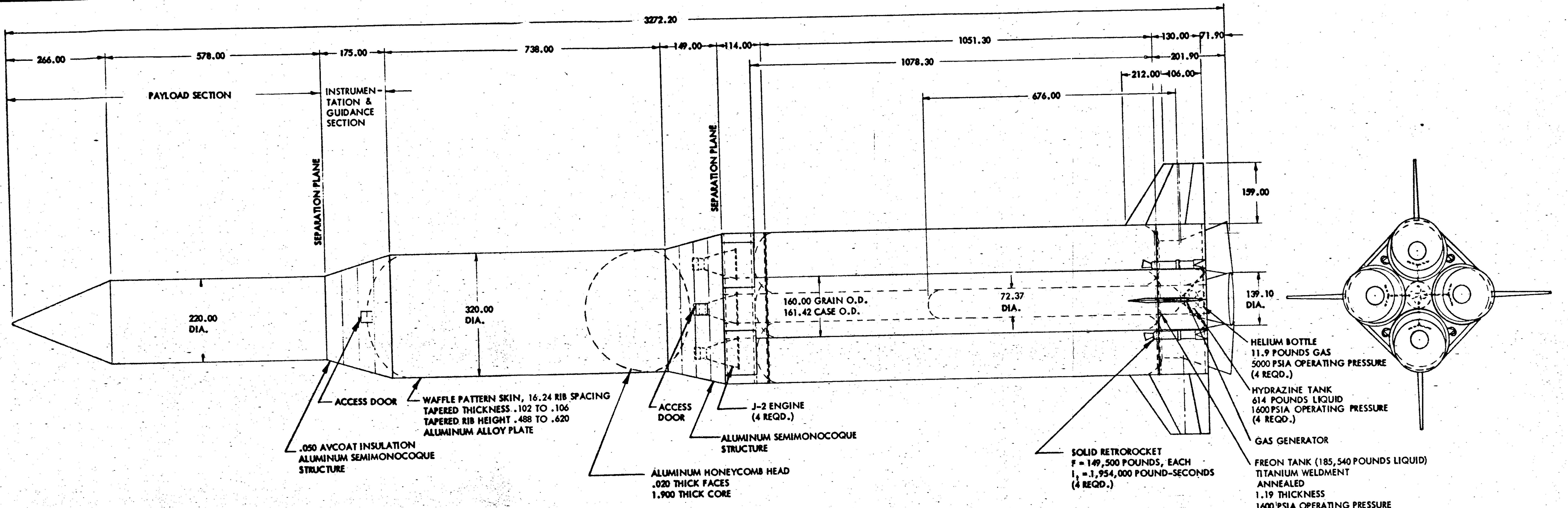


Fig. IV E-1 4-UC4 VEHICLE 180,000-POUND PAYLOAD

Solid-Motor Stage

Four solid motors of a unitized design are clustered for the first stage. An internally burning case-bonded grain using a five-point star perforation is employed in the booster design (see Table IVE-1). A constant port cross section is used in the forward 85 percent of the grain. The remainder of the grain incorporates a divergent taper to provide constant mass flow of gases per unit port area. An 83-percent average cross-sectional propellant loading is used.

Ignition is by individual launcher-retained pyrogen units incorporating complete redundancy.

Silica-filled synthetic-rubber insulation is used in the end closures. In these areas the insulation is tapered from a maximum at the point of initial flame exposure to zero thickness at a point equivalent to the web thickness from the initial exposure point. A synthetic-rubber liner over the entire chamber surface provides the case-to-grain bond. A boot, located in the dome ends, allows for longitudinal grain shrinkage during the propellant-cure cycle (see Figure IVB-2).

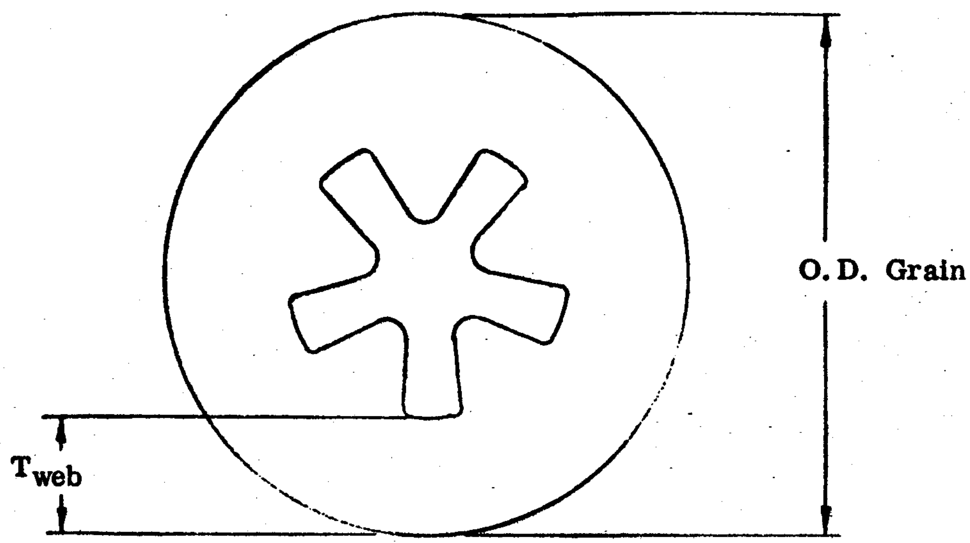
Vehicle-Control System

Flight of the vehicle during booster operation is controlled by the injection of pressurized Freon into the exhaust stream of the fixed nozzles. Injectant ports in the nozzle exit cones control pitch, yaw and roll.

The hydrazine-gas generating system, which provides the fluid working pressure, is located between the booster nozzles and consists of a set of helium-pressurized hydrazine tanks feeding a common gas generator. Although there is sufficient space in the center of the cluster for a tandem grouping of spherical helium bottles ahead of the Freon tank, the intended design growth from the 3-SC4 and/or 3-UC4 vehicles dictated the use of a similar pressurization system in the subject vehicle. (See Figure IVA2-8.) A single cylindrical tank in the center of the booster-motor cluster is used to store the Freon. Gas produced by the generator is fed through a pipe to the forward end of the Freon tank, providing a back pressure to force

Table IVE-1

SUMMARY DESCRIPTION OF MOTOR FOR VEHICLE CONFIGURATION 4-UC4



Grain Outside Diameter, inches	160
Motor Overall Length, inches	1,280.4
Type	Unitized
Thrust, Average During Web Burning Time, lbs*	2,310,320
Web Burning Time, seconds	119.46
Action Time, seconds	125.75
Action Time Impulse, lb-sec	269,868,480
Chamber Pressure, Average During Web Time, psia	800
Specific Impulse, Average During Web Time, seconds	240
Nozzle Configuration	
Expansion Ratio	8
Cant Angle, degrees	5
Motor Weight, Excluding Thrust-Vector-Control System, lbs	1,274,110
Total Propellant Weight, Loaded, lbs	1,124,450
Weight of propellant remaining at end of action time, one percent per motor.	11,240
Motor Effective Mass Fraction, Wt. useful propellant/Wt. motor	0.89
Grain Configuration	Star Port
Cross Section Loading, percent	83
Web Fraction (web thickness/grain radius)	0.44
Web Thickness, inches	35.2
Grain Length/Outside Diameter Ratio	6.74
Grain Port/Nozzle Throat Ratio (aft section of grain is tapered)	1.80 to 2.00

*Motor performance values are given for sea level and 80°F.

the Freon into the tank sump and injector feed lines. The feed lines are fitted with flexible couplings to permit relative longitudinal motion of the motors. Pressures are 5000 psi in the helium bottles and 1600 psi in the hydrazine tanks, gas generator, Freon tank, and feed lines. Injector-valve actuation is by electrical signal from the guidance system. Complete mechanical and electrical redundancy is provided in this area.

Four solid staging rockets, located in the vehicle's base structure, are used during first-stage separation to produce a relative deceleration of the spent booster (with respect to the second stage) of 1.0 g for 3 seconds. Primacord severs the interstage connection. Ullage rockets provide 1.0 g acceleration of the second stage for 5 seconds prior to ignition of the J-2 engines.

Second-stage pitch, yaw, and roll are controlled by full gimbaling of the J-2 engines.

External Insulation

A laminated-fiberglass heat shield with a low-temperature ablative coating is incorporated for booster base-heat protection. The base of the second stage is also provided with a low-temperature ablative coating for this purpose.

The forward interstage is protected from aerodynamic heating by an external layer of Avcoat ablative insulation. External insulation is provided for the liquid-hydrogen pipe line.

PERFORMANCE

The 180,000-pound-payload tandem-design vehicle has a second-stage thrust of 800,000 pounds, provided by four J-2 engines. An initial thrust-to-weight ratio of 1.5 resulted in a maximum dynamic pressure of 1220 psf, indicating that a slightly lower thrust-to-weight ratio may be required for this vehicle. The dynamic pressure at first-stage burnout is 92 psf. The second-stage thrust-to-weight ratio is 0.854.

The trajectory parameter time histories are shown in Figure IVE-2. The velocity-altitude history for the vehicle is shown in Figure IVE-3. A large first-stage boost velocity is required for this vehicle because of the relatively low thrust of the second stage; a low payload-to-launch weight ratio of 0.029 resulted for the vehicle.

STRUCTURAL CHARACTERISTICS OF THE 4-UC4 VEHICLE

Booster Motor Case Construction

The motor cases are fabricated from rolled and welded cylindrical sections of high-strength steel of a size compatible with existing heat-treat facilities. Forged rings of high-strength steel are welded to the ends of each section prior to heat-treat. These rings are of sufficient proportions to permit an "as welded" joint to be made between the sections after heat-treat, as shown in Figure IVA3-15. Therefore, a continuity of the parent-metal strength is maintained.

The 1.4:1 semiellipsoidal end closures are high-strength steel assemblies machined to the proper size, shape, and concentricity. Integral stub skirts are machined into the closure and cylindrical extensions are welded to the skirts to provide tie-ins for the base and interstage structures. The closure bosses are machined forgings that are welded to the parent sections. The individual sections are heat-treated to 200,000-psi ultimate tensile strength prior to assembly.

Nozzle Construction

The convergent (or entrance-cap) portions of the nozzles are formed of pressure-molded silica phenolic and covered with a heavy layer of silica-filled synthetic-rubber insulation. The throat sections are assemblies of pressed graphite blocks backed with monolithic sections of molded silica-phenolic. The divergent portions of the nozzles (or exit cones) are of oriented silica fiber-phenolic construction. The entire assemblies are encased in a steel outer shell, which receives the structural loads.

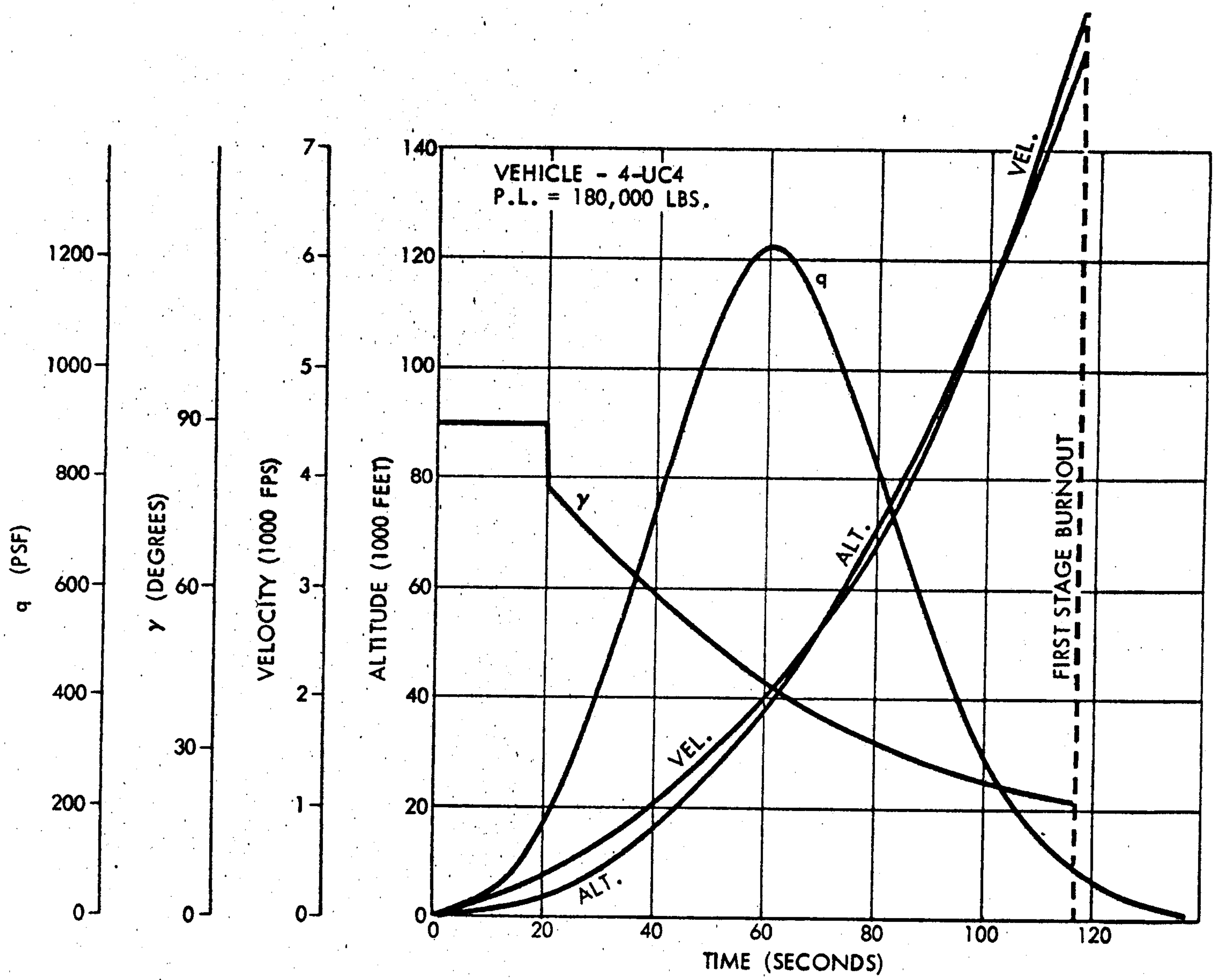


Fig. IV E-2 NASA SOLID STUDY
VEHICLE 4-UC4

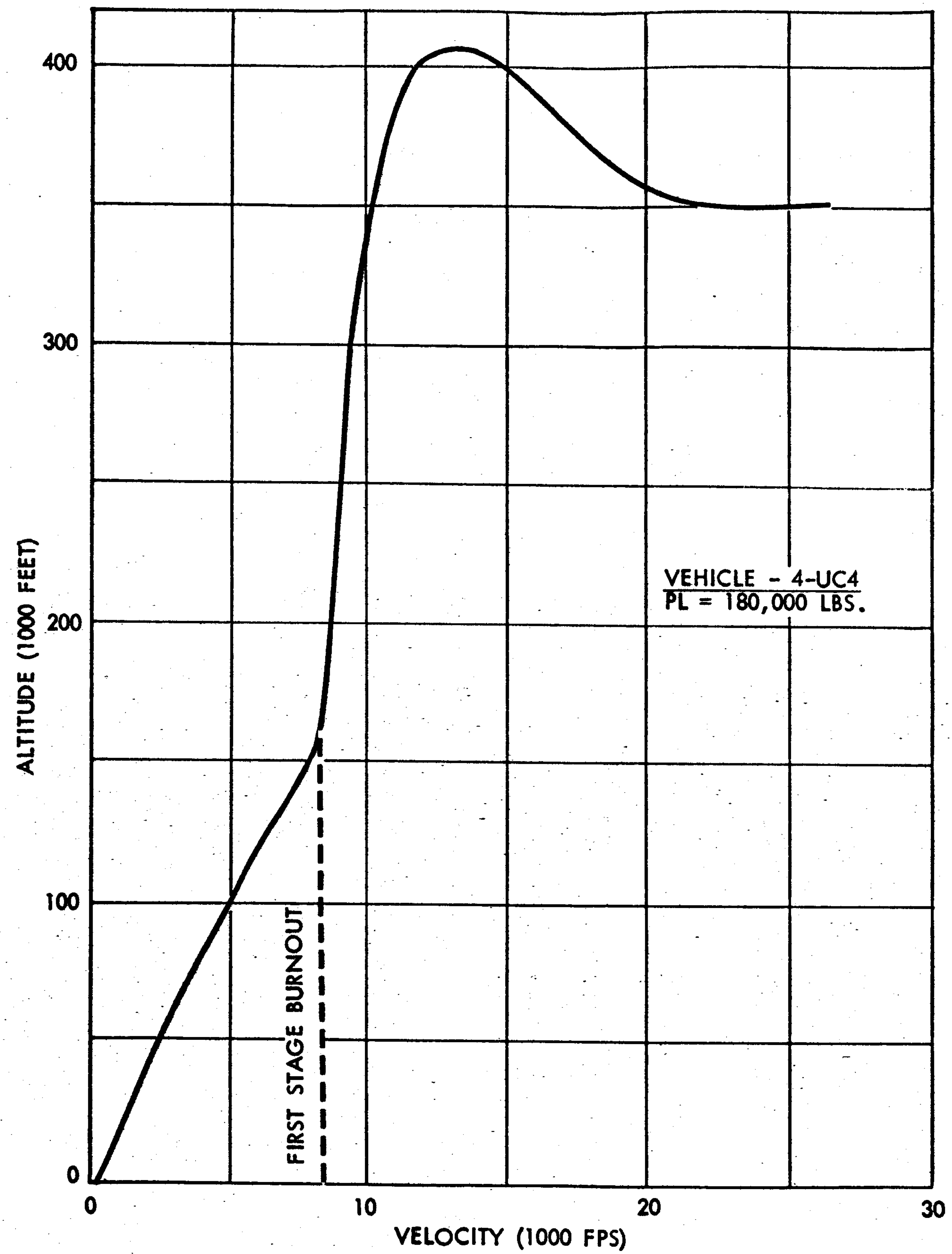


Fig. IV E-3 NASA SOLID STUDY VEHICLE 4-UC4

Vehicle Base Structure

The vehicle launch support structure consists of four cylindrical sections of smooth aluminum-alloy skin reinforced internally with circular aluminum frames. These sections are attached to the base of the booster motors at the aft-skirt extensions. Two of the frames in each section are aluminum channels mounted back-to-back to receive the fin spars. The secondary frames are equally spaced aluminum "zee" sections. A third, channel-type frame at the base of each cylindrical section mates with the vehicle launcher pallet. This member also serves as a staging-rocket support and thrust structure. The forward portions of the fins are attached to the aft weld joint on the booster cases. The aluminum-alloy material used throughout the base structure is heat-treated to 70,000-psi ultimate tensile strength.

Interstage and Intrastage Structure

The aft interstage structure, located between the solid and liquid stages, is divided into two major parts; the case extensions, or barrel sections (see Figure IVA3-16); and the transition section (see Figure IVA3-17).

Each barrel section consists of a smooth cylindrical outer skin of aluminum alloy reinforced at either end with a circular aluminum I-beam and stiffened with intermediate frames. The lower beam in each barrel section is attached to a corresponding skirt at the forward end of each booster motor.

Structural loads are carried from the barrel sections to the second-stage aft skirt by the interstage transition section. This structure consists of a geometrically contoured smooth aluminum outer skin reinforced internally with a series of frames and longitudinal stiffeners.

A central weldment of aluminum alloy tubing to which the interstage barrel sections are attached, and a beam-reinforced shear panel mounted between the outer extremities of each pair of barrel sections comprises the upper clustering structure. The clustering tie is completed by sliding-link attachments between the base structures of each motor, providing lateral restraint but permitting relative longitudinal motion of the motor.

The forward interstage structure, which secures the second-stage tankage to the payload compartment, is of comparable construction to the aft interstage barrel sections. Vehicle guidance, telemetry, and environment-control subsystems are mounted inside this structure on a framework of aluminum-alloy tubes.

Aluminum alloy with ultimate tensile strength of 70,000 psi is used throughout the interstage and intrastage structures.

Second-Stage Construction

The liquid propellants are carried in integral tanks constructed of aluminum-alloy plate machined on the inner surface to produce waffle-pattern ribs and rolled to the proper curvature. The rib height is tapered longitudinally to provide the necessary strength at any station with minimum structural weight. End bulkheads are 1.4:1 semiellipsoids of spun-aluminum construction welded to the waffle structure.

A common hemispherical bulkhead of aluminum-alloy honeycomb construction divides the tankage into two compartments, the liquid oxygen being aft. The tank ullage pressures are 27 psia for the hydrogen and 31 psia for the oxygen. The hydrogen pipelines bypass the oxygen compartment externally.

A trusswork of aluminum-alloy tubes acts as support and thrust structure for the J-2 engines.

TVC Tank Mounting

The TVC tanks are mounted within the first-stage cluster. The upper end of the Freon tank is located approximately 35 feet below the base of the cluster structure. The tank is suspended from the cluster structure by a tension-compression tube and is laterally restrained by sliding supports on the motor cases.

First-Mode Bending Frequency

The first-mode bending frequency of this vehicle is approximately 0.7 cps. Methods of increasing first-mode frequencies are discussed in Section IVA3.

PROPULSION

The first stage of the 4-UC4 vehicle is a cluster of four 160-inch unitized motors. Table IVE-1 is a summary description of the motors, and Table IVE-2 of the motor subsystems. The motors are similar in all respects to those of the 3-UC4 vehicle.

Table IVE-2

MOTOR SUBSYSTEMS FOR 4-UC4 VEHICLE

180,000-Pound Payload

IGNITION SYSTEM

Type: Launch-Retained Pyrogen

THRUST VECTOR CONTROL SYSTEM

Type: Freon 114B2 Injection	
Maximum Total Side Force Required, lbs	182,000
Total Control Impulse Required, lb-sec	16,307,860
Maximum Total Freon Flow Rate, lbs/sec	2,680
Total Freon Weight, lbs	186,860
Total Freon Volume, ft^3	1,448
Freon Pressure, psia	1,600
Hydrazine Monopropellant Freon Pressurization System	
Thermal Decomposition Chamber Length, inches	18.6
Thermal Decomposition Chamber, (L/D)	2
Total Hydrazine Weight, lbs	1,311
Total Hydrazine Volume, ft^3	21.0
Maximum Hydrazine Flow Rate, lbs/sec	18.81
Helium Pressure, psia	5,000
Total Helium Weight, lbs	60.5
Total Helium Volume, ft^3	17.56

DESTRUCT Jet-Perforator

FLIGHT CONTROL

The 180,000-pound-payload C-4 type of tandem vehicle has a slightly larger first-stage cluster diameter than the upper stage, resulting in an overall vehicle fineness ratio of 8.3. A summary of the stability and control characteristics for this vehicle is presented in Table IVE-3. The maximum thrust-vector angle required is 1.7 degrees and the total control-system impulse is 1.6 percent of the main-stage impulse.

The first-mode body-bending frequency for this vehicle is approximately 0.7 cps, which is 4.5 times the minimum pitch-control frequency. This is considered a marginal ratio and structural-coupling problems may require a lower overall fineness ratio, increased structural stiffening, or a lower pitch frequency through decreased vehicle instability.

WEIGHTS

A summary weight statement for Vehicle 4-UC4 is presented in Table IVE-4; detailed weight statements for the oxygen/hydrogen stage and the solid-propellant stage are also presented in Table IVE-4. These weights are based on criteria used for weight-analysis purposes, as presented in Section IVA4. (The primary criteria used for weight-estimating purposes are summarized in Table IVA4-1 for the solid-propellant stages and in Table IVA4-5 for the oxygen/hydrogen stages.)

Table IVE-3

STABILITY AND CONTROL CHARACTERISTICS

Vehicle 4-UC4

180,000-Pound Payload, C-4 Type Tandem-Design Booster

	Maximum q No Fins	Maximum q Fins	First-Stage Burnout	Second-Stage Startburn
Total fin size*, ft^2	0	700	700	0
C_{N_α}, per degree	0.05	0.064	0.056	0.04
C.P., fraction length aft of nose	0.45	0.54	0.45	0.38
C.G., fraction length aft of nose	0.69	0.69	0.54	0.79
q, psf	1200	1200	92	60
M_α, $\frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	163	123	6.8	6.6
M_δ, $\frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	630	630	--	18.4
M_α / M_δ	0.26	0.20	--	0.36
I, slug—$ft^2 \times 10^{-6}$	281	281	179	52.8
M_α / I, sec^{-2}	0.58	0.44	0.038	0.125
t_{2A}, time to double amplitude, seconds	1.7	2.0	6.8	3.8
Maximum required thrust deflections				
For wind, degrees	1.6	1.20	--	
For misalignment, degrees		0.46		
Total, degrees		1.66		
Cant angle required, degrees			5	

*4 fins of 175 ft^2 each.

Table IVE-4

WEIGHT STATEMENT, VEHICLE 4-UC4

Summary Weights

Payload (includes G&C Instrumentation)	(180,000)
Second-Stage Inert Weight at Burnout	(71,320)
Dry Weight	43,940
Reserve Propellant	15,080
PU Allowance	6,840
Gas Residuals	3,940
Trapped Propellant	1,520
VEHICLE WEIGHT AT SECOND-STAGE BURNOUT	(251,320)
Second-Stage Main-Stage Propellant	(684,920)
Fuel, LH_2	114,150
Oxidizer, LO_2	570,770
VEHICLE WEIGHT AT SECOND-STAGE IGNITION	(936,240)
Second-Stage Items Expended During Separation/Start	(4,070)
Propellant for Chilldown/Start	2,200
Ullage-Rocket Propellant	1,870
First-Stage Inert Weight at Burnout	(598,640)
Dry Weight	532,760
Sliver	44,980
Trapped Injectant, TVC System	16,870
Pressurant, TVC System	4,030
VEHICLE WEIGHT AT FIRST-STAGE BURNOUT	(1,538,950)
First-Stage Expected Propellant Consumption	(4,666,480)
Solid Propellant	4,497,810
Injectant, TVC System	168,670
VEHICLE WEIGHT AT LIFTOFF	(6,205,430)

Table IVE-4

Detailed Weight Statement, Second Stage

Structure:	(29,620)
Tankage	14,580
Antislosh and Vortex Provisions	1,220
Insulation, Tank	2,480
Forward Interstage	2,450
Aft Skirt	4,830
Thrust Structure	2,430
Base-Heat Protection	1,100
Separation Provisions	120
Contingency	410
Propulsion System and Accessories:	(12,650)
Engine Package (Dry)	8,120
Propellant-Distribution System	500
Pressurization Equipment	350
Fill and Drain System	140
Vent System	90
Propellant Loading/Utilization System	70
TVC System	800
Staging-Rockets Group	2,170
Contingency	410
Equipment:	(1,670)
Control Elements	20
Telemetry	640
Environment-Control Provisions	40
Power Supply and Electrical Network	775
Range Safety and Destruct Systems	50
Contingency	145
Unusable Propellant and Gas Residuals:	(5,460)
Propellant in Engine Package	360
Propellant in Lines	1,080
Gaseous Hydrogen	840
Gaseous Oxygen	2,740
Helium Slugs	180
Contingency	260
Usable Propellant Residuals:	(21,920)
Propellant-Utilization Allowance	6,840
Reserve Propellant	15,080
STAGE WEIGHT AT BURNOUT	(71,320)

Table IVE-4

Detailed Weight Statement, Second Stage (Cont.)

Main-Stage Propellant:	(684,920)
STAGE WEIGHT AT IGNITION	(756,240)
Items Expended Prior to Ignition:	(4,070)
Ullage-Rocket Propellant	1,870
Propellant for Childown/Start	2,200
STAGE WEIGHT PRIOR TO IGNITION	(760,310)
STAGE MASS FRACTION AT IGNITION	0.9057

Detailed Weight Statement, First Stage

Basic Motor:	(390,500)
Forward Bulkhead	14,840
Cylinder	301,400
Aft Bulkhead	21,200
Nozzle	26,880
Insulation and Liner, Forward Bulkhead	1,360
Insulation and Liner, Aft Bulkhead	7,560
Liner, Cylinder	8,240
Contingency	9,020
TVC System (Dry):	(79,860)
Tankage, Freon	18,370
Tankage, Helium	53,360
Controls, Plumbing and Supports	8,130
Equipment:	(1,180)
Control Elements	20
Telemetry	440
Environment-Control Provisions	50
Power Supply and Electrical Network	610
Contingency	60
Structural Provisions:	(51,080)
Clustering Structure	26,000
Forward Interstage	6,760

Table IVE-4

Detailed Weight Statement, First Stage (Cont.)

Aft Skirts	5,780
Fins	4,540
Base-Heat Protection	3,100
Separation Provisions	120
Contingency	4,780
Separation Rockets:	(10,140)
Propellant	7,060
Rocket Inerts	2,370
Attachment Fittings	710
Unusable Propellant and Residuals:	(65,880)
Sliver	44,980
Freon Residual	16,870
Helium, TVC System	4,030
STAGE WEIGHT AT BURNOUT	(598,640)
Expected Propellant Consumption:	(4,666,480)
Main-Stage Propellant	4,497,810
Freon	168,670
STAGE WEIGHT AT LIFTOFF	(5,265,120)
STAGE MASS FRACTION AT LIFTOFF	0.8863

F. 180,000-POUND-PAYLOAD VEHICLE—LATERAL DESIGN (4-UC6L)

1. DESCRIPTION AND ANALYSIS

GENERAL DESCRIPTION

Vehicle 4-UC6L, shown in Figure IVF-1, is a two-stage system incorporating six unitized solid-propellant booster motors clustered laterally around a liquid-oxygen/liquid-hydrogen powered second stage. Four J-2 engines supply second-stage thrust. Fixed fins at the base of the booster motors reduce vehicle instability. Aerodynamic and base-heat protection is furnished. Secondary fluid injection is used for booster thrust-vector control.

Concept Evolution

The subject vehicle was considered as an alternate to the 4-UC4 tandem design to compare the relative effects of the two booster arrangements on the system designs. Concepts using clusters of four, five, six, seven, and eight booster motors with 160-inch grain diameters were considered in the design-development series. A four-motor arrangement was attempted to maintain the reliability of the tandem design; however, the increased booster propulsion requirement for the laterally staged design required a length prohibitive to internal ballistic efficiency in thi3 number of motors. Eight motors permit the tightest grouping and provide a lighter and more rigid clustering structure, but the adverse effects on stage and vehicle reliability offset these advantages. The six-motor cluster proved the most feasible of the intermediate clusters considered for the lateral application. The liquid-stage tankage diameter was reduced over that of the tandem design to permit closer grouping of the booster motors and to provide a more efficient vehicle fineness ratio. The payload size is identical to that of vehicle 4-UC4.

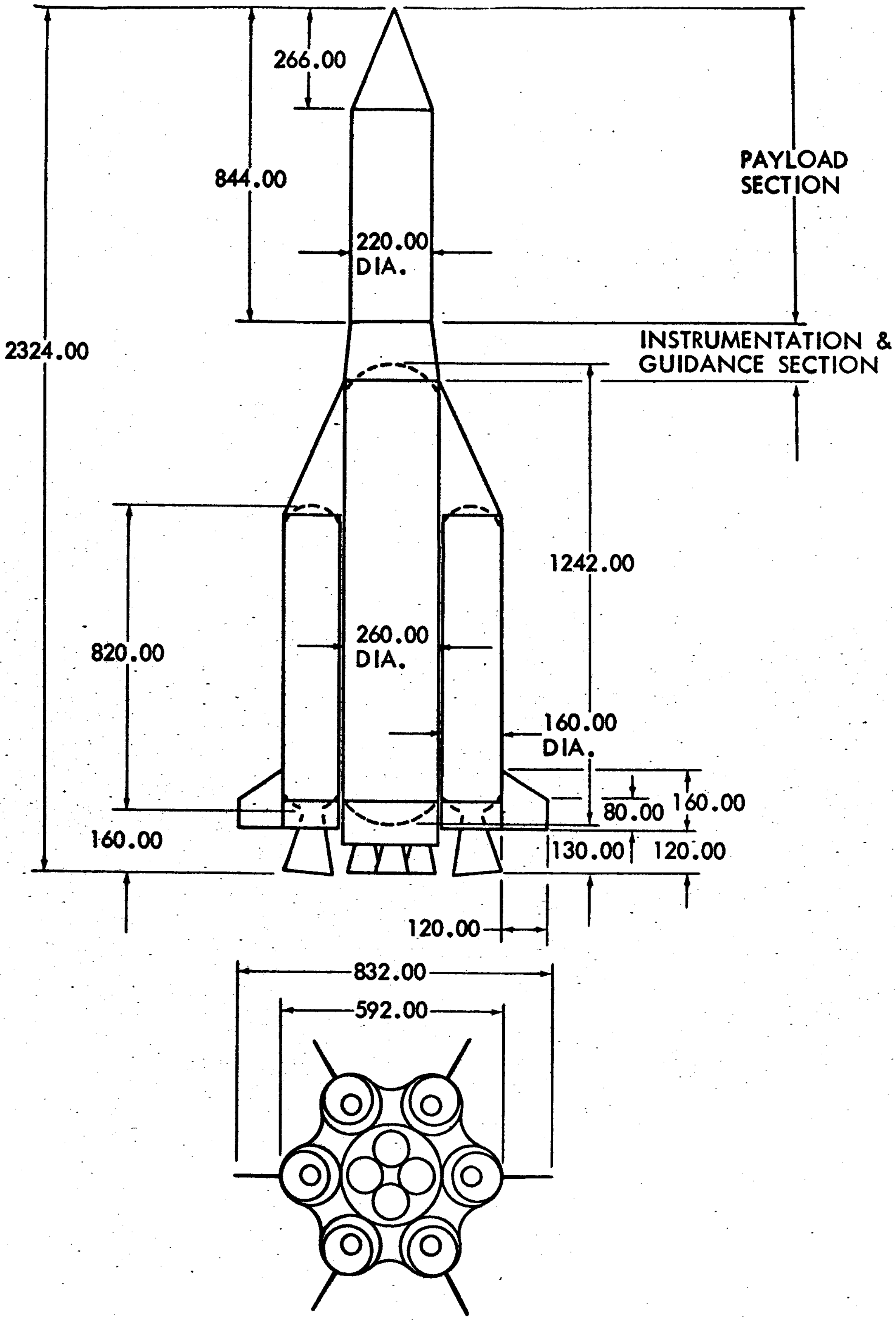


Fig. IV F-1 4-UC6L VEHICLE 180,000 POUND PAYLOAD

PERFORMANCE

The 180,000-pound-payload lateral-design vehicle has four J-2 engines in the second stage to provide a thrust of 800,000 pounds. An initial thrust-to-weight ratio of 1.5 is used to provide a maximum dynamic pressure of 1150 psf. First-stage burnout dynamic pressure for this vehicle is 105 psf. The second-stage thrust-to-weight ratio is 0.847.

The trajectory parameter time histories for this vehicle are shown in Figure IVF-2. The velocity-altitude history for this vehicle is shown in Figure IVF-3. This vehicle had the largest first-stage boost velocity of the six vehicle studied, resulting in the lowest payload-to-launch weight ratio of 0.0263.

STRUCTURAL CHARACTERISTICS OF THE 4-UC6L VEHICLE

All structures are similar to the 4-UC4 tandem design with the exception of the interstage and intrastage structures. Two general methods of first-stage separation were considered in designing these structures.

The first method involved a hinged attachment of the individual booster motors to the base structure of the liquid stage. The forward clustering tie is accomplished through axially sliding attachments of the forward booster skirts to a circular frame located inside the hydrogen tank. At stage separation each motor is severed at the forward interstage tie and is accelerated radially outward about its base hinge point by a small vectoring rocket. At a predetermined time the J-2 engines are ignited, the second-stage base structure is severed, and the deceleration forces imparted to the empty booster assembly carry it clear of the second stage.

The second method differs from the first primarily in that the stages maintain their lateral relationship during separation. The booster cases are linked to the liquid tankage by interlocking rails. The aft skirts of the boosters are connected to the base structure of the second stage through a rigid framework. On signal

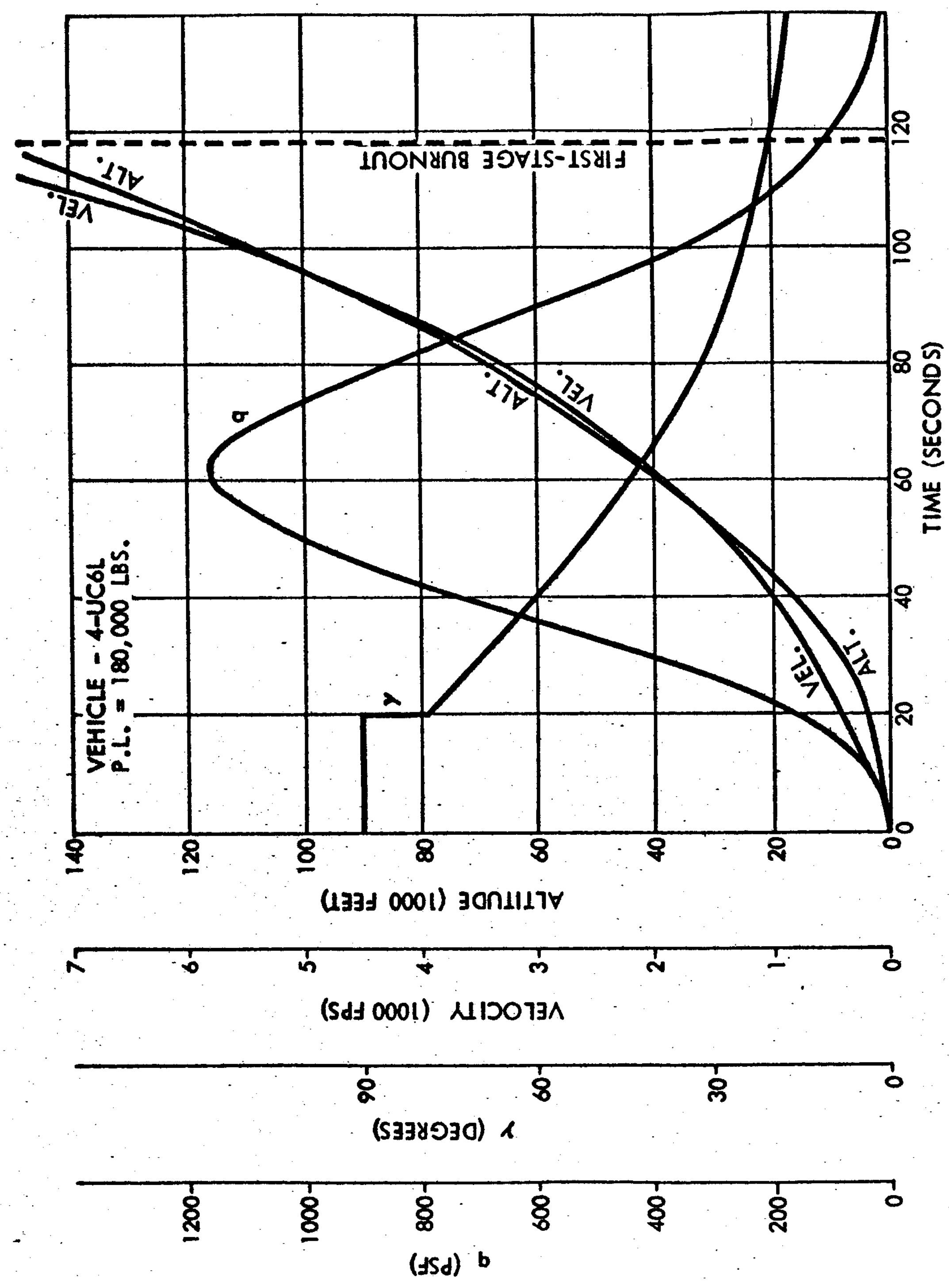


Fig. IV F-2 NASA SOLID STUDY
4-UC6L

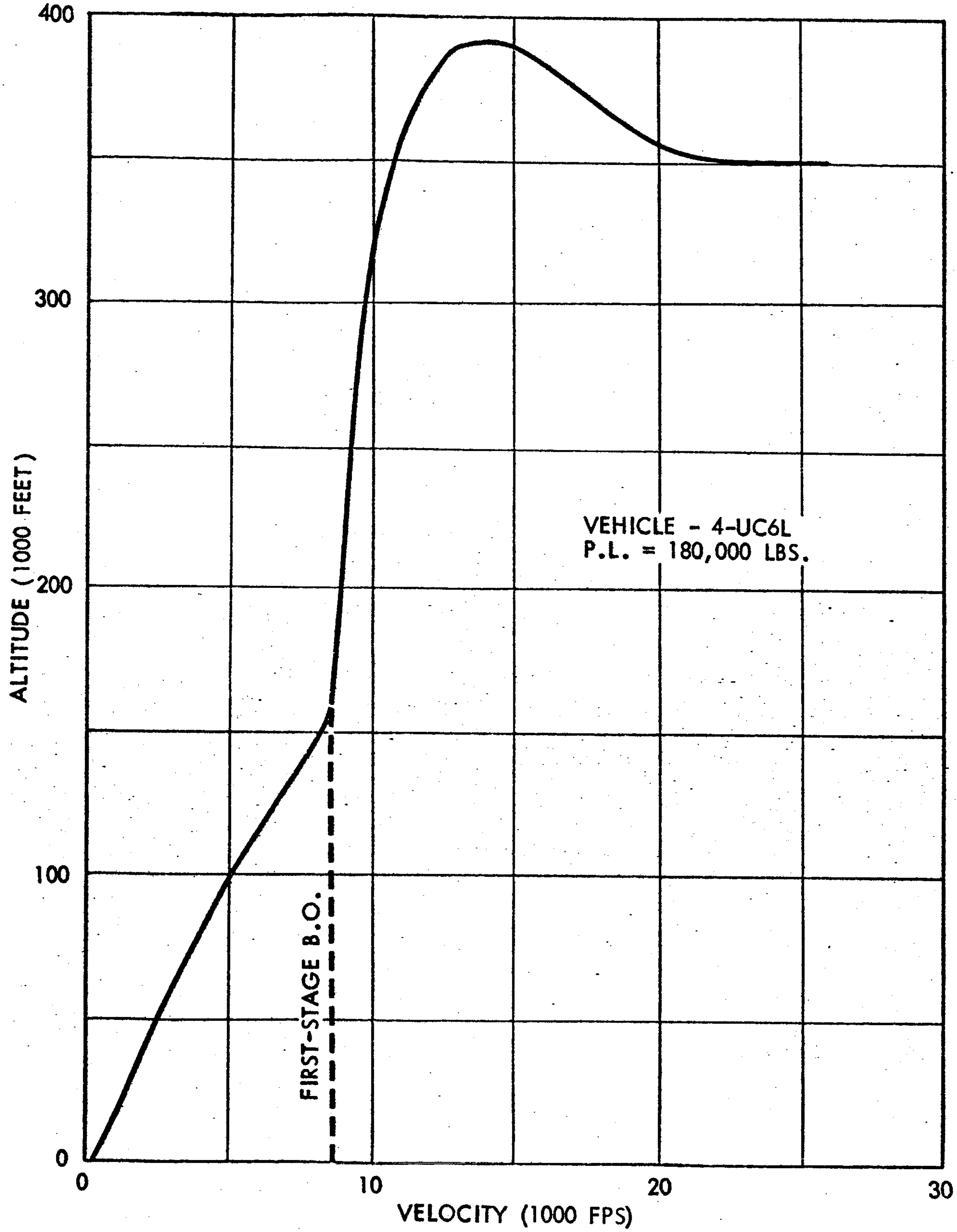


Fig. IV F-3 NASA SOLID STUDY
VEHICLE 4-UC6L

the J-2 engines are ignited, the second-stage aft skirt is severed ahead of the base framework, and the retrorockets are fired to decelerate the spent booster assembly, which is guided clear of the second stage by the interstage rails.

Either method appears to require approximately the same structural weight. A more comprehensive analysis of the relative merits of the two systems was not possible in the time allotted.

A structural analysis was not performed on this configuration. A review of previous studies on vehicles of this type point out special load-path requirements. The second stage of the vehicle will be designed to carry the entire vehicle bending load in addition to the normal axial loads.

PROPULSION

First-stage propulsion requirements of the laterally staged 4-UC6L vehicles are met by a cluster of six unitized 160-inch motors.

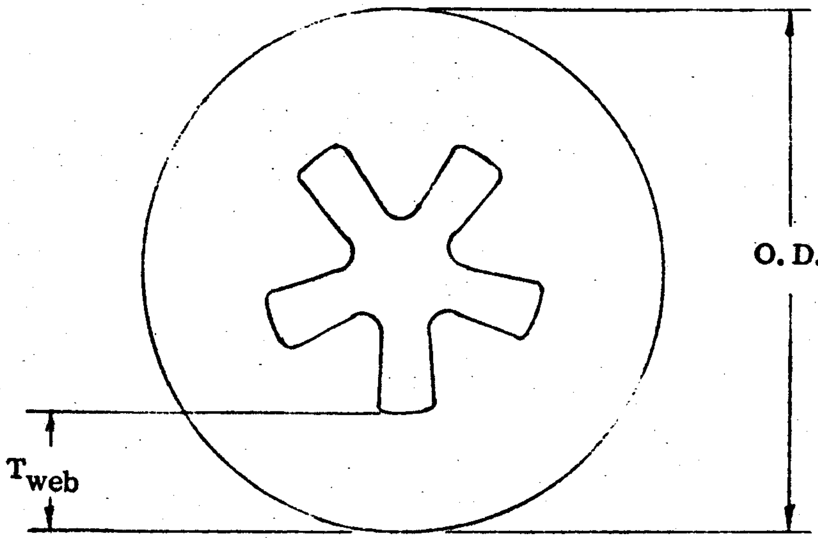
Summary description of the motor is presented in Table IVF-1. Motor subsystems are described in Table IVF-2.

Nozzle cant angle is not defined. To pass the thrust lines through the vehicle center of gravity at first-stage burnout would require about 15 degrees of cant. This would entail 3.4 percent vector loss of impulse, and may impose some nozzle-development problems associated with flow turning and the long duration involved.

The second stage of this configuration could be ignited at the occurrence of thrust decay of the first stage; this would provide some thrust-vector control late in the first-stage tailoff without exceeding the maximum acceleration for which the vehicle is designed. With the second-stage engine-control force then available, the cant angle of the first-stage motors could be reduced.

Table IVF-1

SUMMARY DESCRIPTION OF MOTOR FOR VEHICLE CONFIGURATION 4-UC6L



Grain Outside Diameter, inches	160
Motor Overall Length, inches	980.4
Type	Unitized
Thrust, Average During Web Burning Time, lbs *	1,693,240
Web Burning Time, seconds	121.36
Action Time, seconds	127.75
Action Time Impulse, lb-sec	200,936,790
Chamber Pressure, Average During Web Time, psia	800
Specific Impulse, Average During Web Time, seconds	240
Nozzle Configuration	
Expansion Ratio	8
Cant Angle, degrees	not defined
Motor Weight, Excluding Thrust-Vector-Control System, lbs	947,460
Total Propellant Weight, Loaded, lbs	837,240
Weight of propellant remaining at end of action time, one percent per motor.	8,370
Motor Effective Mass Fraction, Wt. useful propellant/Wt. motor	0.89
Grain Configuration	Star Port
Cross Section Loading, percent	83
Web Fraction (web thickness/grain radius)	0.44
Web Thickness, inches	35.2
Grain Length/Outside Diameter Ratio	5.06
Grain Port/Nozzle Throat Area Ratio	2.44

*Motor performance values are given for sea level and 80°F.

Table IVF-2

MOTOR SUBSYSTEMS FOR 4-UC6L VEHICLE
180,000-Pound Payload

IGNITION SYSTEM

Type: Launch-Retained Pyrogen

THRUST-VECTOR-CONTROL SYSTEM

Type: Freon 114B2 Injection	
Maximum Total Side Force Required, lbs	156,000
Total Control Impulse Required, lb-sec	18,219,140
Maximum Total Freon Flow Rate, lbs/sec	2,298
Total Freon Weight, lbs	208,760
Total Freon Volume, ft^3	1,618
Freon Pressure, psia	1,600
Hydrazine Monopropellant Freon Pressurization System	
Thermal Decomposition Chamber Length, inches	17.7
Thermal Decomposition Chamber, (L/D)	2
Total Hydrazine Weight, lbs	1,465
Total Hydrazine Volume, ft^3	23.4
Maximum Hydrazine Flow Rate, lbs/sec	16.12
Helium Pressure, psia	5,000
Total Helium Weight, lbs	67.6
Total Helium Volume, ft^3	19.62

DESTRUCT Jet-Perforator

Staging of this vehicle was not studied in detail. Control during the staging sequence, even if thrust termination were provided, appears to be a difficult problem.

FLIGHT CONTROL

The 180,000-pound-payload C-4 type of lateral design was configurated to show some of the effects of lateral staging on booster design. The mounting of the six first-stage solid-booster motors on the side of the second stage results in a low overall vehicle fineness ratio of 3.8. A total required fin area of 600 square feet is obtained from six equally sized fins mounted on the first-stage motors. This is not greatly different from the 700-square-foot total required by the tandem staged vehicle. Even though slightly more favorable stability and inertia characteristics exist for the laterally staged vehicle, the larger base area largely offsets these. A summary of the stability and control characteristics for this vehicle is presented in Table IVF-3. The maximum thrust-vector angle required is 1.6 degrees and the total control-system impulse is 1.9 percent of the main-stage impulse.

Stage separation for the lateral design causes additional problems compared to the tandem design. A nozzle cant angle of about 15 degrees is required to aim the thrust through the center of gravity at burnout. This angle dictates an auxiliary control scheme for this vehicle. Stage-separation problems would probably fix the maximum side force requirements for any type of control system. In addition, it may be difficult to develop a method for the separation of the six motors, either as integral units or as individual modules.

The one apparent advantage to this configuration is its relatively short overall length and associated high first-mode body-bending frequency. Although this parameter was not calculated, it is expected to be over 1.5 cps and hence will provide at least a factor of 10 over the minimum pitch-control frequency. This would indicate minimum structural-coupling problems.

Table IVF-3

STABILITY AND CONTROL CHARACTERISTICS
VEHICLE 4-UC6L

180,000-Pound-Payload C-4 Type of Lateral-Design Booster

	Maximum q No Fins	Maximum q Fins	First Stage Burnout	Second Stage Startburn
Total fin size*, ft^2	0	600	600	0
$C_{N\alpha}$, per degree	0.04	0.046	-	0.04
C.P., fraction length aft of nose	0.60	0.63	0.63	0.42
C.G., fraction length aft of nose	0.69	0.69	0.57	0.46
q, psf	1200	1200	105	75
M_α, $\frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	83.1	65.6	-	0.4
M_δ, $\frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	430	430	-	78.4
M_α / M_δ	0.19	0.15	-	0.07
I, slug - $ft^2 \times 10^{-6}$	145	145	-	42
M_α / I, sec^{-2}	0.58	0.45	-	0.011
t_{2A}, time to double amplitude, seconds	1.7	2.0	-	12.6
Maximum required thrust deflections				
For wind, degrees	1.1	0.90	-	
For misalignment, degrees		0.74		
Total, degrees		1.64		
Cant angle required, degrees			15	

* 6 fins of 100 ft^2 each

WEIGHTS

A summary weight statement for vehicle 4-UC6L is presented in Table IVF-4; detailed weight statements for the oxygen/hydrogen stage and the solid-propellant stage are also presented in Table IVF-4. These weights are based on criteria used for weight-analysis purposes, as presented in Section IVA-4. (The primary criteria used for weight-estimating purposes are summarized in Table IVA4-1 for the solid-propellant stages and in Table IVA4-5 for the oxygen/hydrogen stages.)

Vehicle 4-UC6L is a laterally staged vehicle with six solid-propellant motors positioned in parallel around the second-stage tank. Staging is accomplished by a track and roller system whereby the first stage is guided aft to clear the second-stage nozzles.

The following discussion is offered to clarify the analysis of weights, which may not be clear when examining the weights and when comparing the weights to the tandem-staged configuration (4-UC4).

It will be noticed that this laterally staged configuration, when compared to the tandem-staged configuration, exhibits very little change in mass fraction for the first stage, but a significant mass-fraction reduction (0.011) for the second stage.

The second-stage weight increases are contributed primarily:

1) By 2300 pounds of carry-through structure in the form of circumferentials on the second-stage tank to react lateral loads transmitted through the tracks;
2) By 1840 pounds of aft-skirt increase due mainly to distributing point loads uniformly into the tank structure (other factors that contrast each other are a length increase and a diameter decrease);
3) By 3180 pounds of additional separation provisions in the form of six rail installations;

Table IVF-4

WEIGHT STATEMENT, VEHICLE 4-UC6L

Summary Weights

Payload (includes G&C Instrumentation)	(180,000)
Second Stage Inert Weight at Burnout	(80,170)
Dry Weight	52,230
Reserve Propellant	15,610
PU Allowance	6,840
Gas Residuals	3,940
Trapped Propellant	1,550
VEHICLE WEIGHT AT SECOND-STAGE BURNOUT	(260,170)
Second-Stage Main-Stage Propellant	(684,390)
Fuel, LH_2	114,060
Oxidizer, LO_2	570,330
VEHICLE WEIGHT AT SECOND-STAGE IGNITION	(944,560)
Second-Stage Items Expended During Separation/Start	(4,070)
Propellant for Chilldown/Start	2,200
Ullage-Rocket Propellant	1,870
First-Stage Inert Weight at Burnout	(661,310)
Dry Weight	587,740
Sliver	50,230
Trapped Injectant, TVC System	18,840
Pressurant, TVC System	4,500
VEHICLE WEIGHT AT FIRST-STAGE BURNOUT	(1,609,940)
First-Stage Expected Propellant Consumption	(5,211,800)
Solid Propellant	5,023,420
Injectant, TVC System	188,380
VEHICLE WEIGHT AT LIFTOFF	(6,821,740)

Table IVF-4 (Cont.)

Detailed Weight Statement, Second Stage

Structure:	(37,650)
Tankage	15,650
Antislosh and Vortex Provisions	1,220
Insulation, Tank	2,850
Forward Interstage	1,960
Carry-Through Structure, Tanks	2,300
Aft Skirt	6,670
Thrust Structure	2,100
Base-Heat Protection	950
Separation Provisions	3,300
Contingency	650
Propulsion System and Accessories:	(12,780)
Engine Package (Dry)	8,120
Propellant-Distribution System	600
Pressurization Equipment	370
Fill and Drain System	140
Vent System	90
Propellant Loading/Utilization System	70
TVC System	800
Staging-Rockets Group	2,170
Contingency	420
Equipment:	(1,800)
Control Elements	20
Telemetry	700
Environment-Control Provisions	40
Power Supply and Electrical Network	835
Range Safety and Destruct Systems	50
Contingency	155
Unusable Propellant and Gas Residuals:	(5,490)
Propellant in Engine Package	360
Propellant in Lines	1,110
Gaseous Hydrogen	840
Gaseous Oxygen	2,740
Helium Slugs	180
Contingency	260
Usable Propellant Residuals:	(22,450)
Propellant-Utilization Allowance	6,840
Reserve Propellant	15,610
STAGE WEIGHT AT BURNOUT	(80,170)

Table IVF-4 (Cont.)

Detailed Weight Statement, Second Stage

Main-stage Propellant:	(684, 390)
STAGE WEIGHT AT IGNITION	(764, 560)
Items Expended Prior to Ignition:	(4,070)
Ullage-Rocket Propellant	1,870
Propellant for Chilldown/Start	2,200
STAGE WEIGHT PRIOR TO IGNITION	(768, 630)
STAGE MASS FRACTION AT IGNITION	0.8951

Detailed Weight Statement, First Stage

Basic Motor:	(441,010)
Forward Bulkhead	22,260
Cylinder	325,740
Aft Bulkhead	31,800
Nozzle	28,620
Insulation and Liner, Forward Bulkhead	2,040
Insulation and Liner, Aft Bulkhead	11,340
Liner, Cylinder	8,980
Contingency	10,230
TVC System (Dry):	(91,400)
Tankage, Freon	20,510
Tankage, Helium	59,720
Controls, Plumbing, and Supports	11,170
Equipment:	(1,260)
Control Elements	20
Telemetry	500
Environment-Control Provisions	50
Power Supply and Electrical Network	630
Contingency	60
Structural Provisions:	(42,870)
Clustering Structure	19,700
Forward Fairings	3,600
Aft Skirts	6,000
Fins	4,540
Base-Heat Protection	3,600
Separation Provisions	1,600
Contingency	3,830

Table IVF-4 (Cont.)

Detailed Weight Statement, First Stage

Separation Rockets:	(11,200)
Propellant	7,830
Rocket Inerts	2,610
Attachment Fittings	760
Unusable Propellant and Residuals:	(73,570)
Sliver	50,230
Freon Residual	18,840
Helium, TVC System	4,500
STAGE WEIGHT AT BURNOUT	(661,310)
Expected Propellant Consumption:	(5,211,800)
Main-stage Propellant	5,023,420
Freon	188,380
STAGE WEIGHT AT LIFTOFF	(5,873,110)
STAGE MASS FRACTION AT LIFTOFF	0.8874

4) By approximately 1000 pounds of miscellaneous weight changes associated with the change in length-to-diameter ratio of the second-stage booster configuration;

5) By 530 pounds of additional reserve propellant required to provide the specified excess velocity for the increased second-stage burnout weight.

Due to second-stage mass-fraction degradation and to first-stage inert-weight changes, it is necessary to increase the weight of first-stage propellant to maintain the vehicle's payload capability. A slight reduction in the first-stage mass fraction would have resulted if the first-stage propellant weight had not been increased.

Comparison of the detail weight statement for the tandem 4-UC4 and lateral 4-UC6L configurations indicate many first-stage weight differences that are a function of the number of motors, weight of propellant, shape (L/D) of the motors, and the staging concept. First-stage clustering structure and forward interstage or fairing show significant weight reductions for the laterally staged configuration. A large portion of the clustering structure is charged to the second stage of the subject vehicle. The forward interstage of the reference vehicle is now used principally as an aerodynamic fairing rather than for transmitting axial and bending loads between tandem stages.

Other concepts of staging and clustering for laterally staged configurations do exist. Considerably more study and detail analysis will be required before obtaining a high level of confidence in the weights of these concepts.

G. 350,000-POUND-PAYLOAD VEHICLE—TANDEM DESIGN (N-UC4)

1. DESCRIPTION AND ANALYSIS

GENERAL DESCRIPTION

Vehicle N-UC4 shown in Figure IVG-1 is a two-stage system incorporating a cluster of four unitized solid rocket motors mounted in tandem with a liquid-oxygen/liquid-hydrogen-powered second stage. Three Y-1 engines supply second-stage thrust. Aerodynamic and base heat protection is furnished. Secondary fluid injection is used for booster thrust vector control.

Concept Evolution

Clusters of various numbers of solid booster motors having 160 inch grain diameters were considered in the design development series. Excessively long motors were required in clusters of fewer numbers and a degradation of stage and vehicle reliability was imposed where larger numbers were exercised. These findings indicated the use of a larger grain. Increasing the grain diameter to 192 inches is considered a feasible means of improving reliability and ballistic design.

Liquid Stage and Payload

A tankage diameter of 396 inches was chosen for the liquid stage. This dimension is compatible with booster size and vehicle fineness ratio. The payload was arbitrarily sized by doubling the diameter of the payload used on vehicle 1-S1, assuming that the cross-sectional density is thereby increased four times. The required payload length was then calculated accordingly.

Solid Motor Stage

The four solid motors are of a unitized design. An internally burning case-bonded grain using a five-point-star perforation is employed in the booster design (see

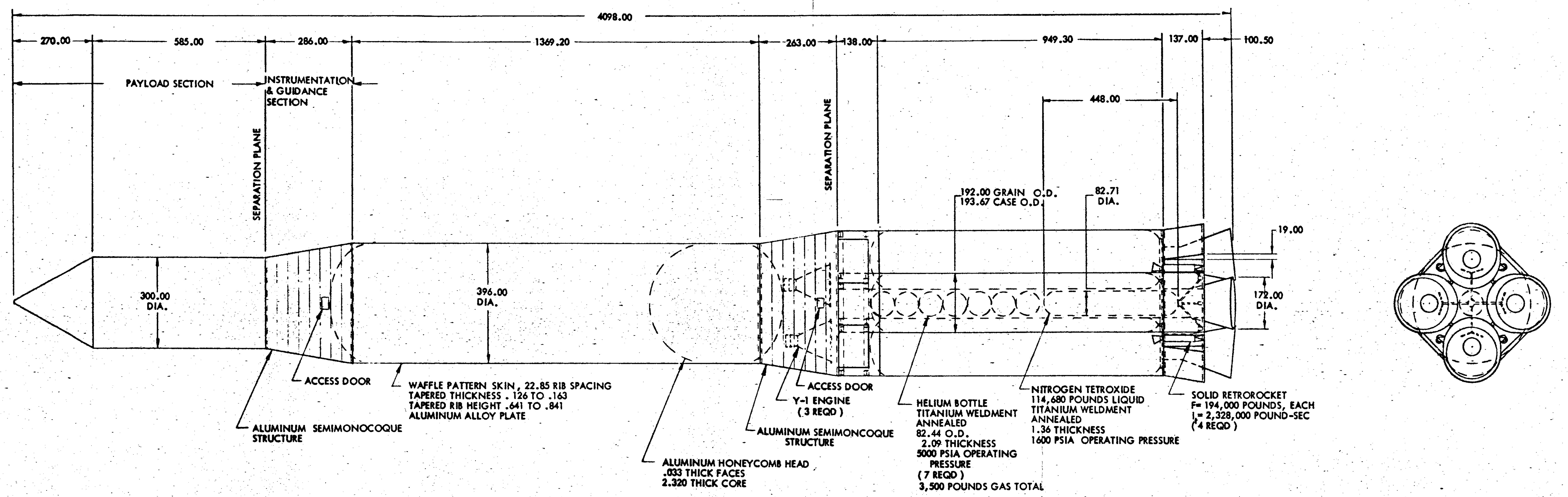


FIGURE IV G-1 N-UC4 VEHICLE 350,000-POUND PAYLOAD

Table IVG-1). A constant port cross section is used in the forward 85 percent of the grain. The remainder of the grain incorporates a divergent taper to provide constant mass flow of gases per unit port area. An 83 percent average cross-sectional propellant loading is used.

Ignition is by individual launcher-retained pyrogen units incorporating complete redundancy.

Silica-filled synthetic rubber insulation is used in the end closures. In these areas, the insulation is tapered from a maximum thickness at the point of initial flame exposure to zero thickness at a point equivalent to the web thickness from the initial exposure point. A synthetic rubber liner over the entire inner chamber surface provides the case to grain bond. A boot, located in the dome ends as shown in Figure IVB-2, allows for longitudinal grain shrinkage during the propellant cure cycle.

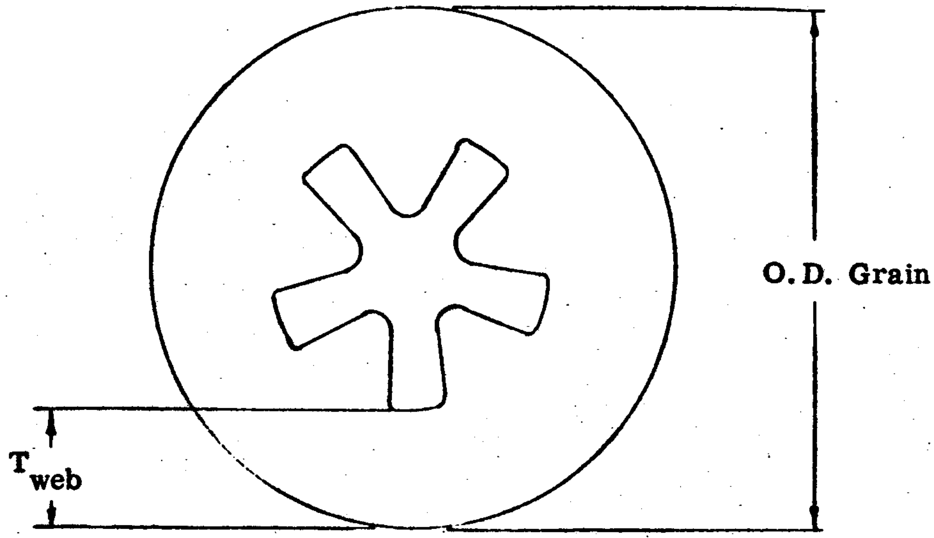
Vehicle Control System

Flight control of the vehicle during booster operation is supplied by the injection of pressurized nitrogen tetroxide into the exhaust stream of the fixed nozzles. Injectant ports located in the nozzle exit cones provide pitch, yaw and roll control. The hydrazine pressurization system used on the 3-SC, 3-UC and 4-UC vehicles was not recommended for the subject vehicle because of the explosive hazard of the hydrazine - N_2O_4 mixture. However, more compatible types of gas generation systems warrant investigation because of the potential weight savings to be realized.

Seven interconnected spherical helium bottles are tandem mounted in the center of the booster motor cluster just ahead of the single cylindrical tank used to store the nitrogen tetroxide. The helium tanks supply pressure to the nitrogen tetroxide through a series of regulators. The injector feed lines are fitted with flexible couplings to permit relative longitudinal motion of the motors. Pressures are 5,000 psi in the helium bottles and 1600 psi in the nitrogen tetroxide tank

Table IVG-1

SUMMARY DESCRIPTION OF MOTOR FOR VEHICLE CONFIGURATION (N-UC4)



Grain Outside Diameter, Inches	192
Motor Overall Length, Inches	1,221.6
Type	Unitized
Thrust, Average During Web Burning Time, Lbs.*	3,542,530
Web Burning Time, Seconds	100.0
Action Time, Seconds	106.10
Action Time Impulse, Lb/Sec	349,151,760
Chamber Pressure, Average During Web Time, Psia	800
Specific Impulse, Average During Web Time, Seconds	240
Nozzle Configuration	
Expansion Ratio	8
Cant-Angle, Degrees	5
Motor Weight, Excluding Thrust Vector Control System, Lbs.	1,649,120
Total Propellant Weight Loaded, Lbs.	1,454,800
Weight of propellant remaining at end of action time, one percent per motor.	14,550
Motor Effective Mass Fraction, Wt. useful propellant/Wt. motor	.886
Grain Configuration	Star Port
Cross Section Loading, percent	83
Web Fraction (web thickness/grain radius)	.44
Web Thickness, Inches	42.2
Grain Length/Outside Diameter Ratio	5.09
Grain Port/Nozzle Throat Area Ratio (aft section of port is tapered)	1.70 to 2.00

* Motor performance values are given for sea level and 80°F

and feed lines. The injector valve is actuated by electrical signal from the guidance system. Complete mechanical and electrical redundancy is provided in this area.

Four solid-staging rockets located in the vehicle base structure are used during first-stage separation to produce a relative deceleration of the spent booster with respect to the second stage of 1.0 g for three seconds. Primacord is used to sever the interstage connection. Ullage rockets provide 0.1 g acceleration of the second stage for five seconds before ignition of the Y-1 engines.

Second-stage pitch, yaw and roll control is supplied by full gimballing of the Y-1 engines.

External Insulation

A laminated fiberglass heat shield with a low temperature ablative coating is incorporated for booster base heat protection. The base of the second stage is also provided with a low temperature ablative coating for this purpose. The forward interstage is protected from aerodynamic heating by an external layer of Avcoat ablative insulation. External insulation is provided for the liquid-hydrogen pipe line.

Vehicle Schedule

Figure IVG-2 presents a detailed design development schedule for the subject vehicle from study inception to first launch. Major milestones and corresponding lead times are indicated.

PERFORMANCE

The 350,000-pound payload vehicle uses three Y-1 engines in the liquid stage, providing a total thrust of 3,000,000 pounds. An initial thrust-to-weight ratio for the vehicle of 1.55 results in a maximum dynamic pressure of 1222 psf, indicating that a slightly lower thrust-to-weight ratio may be required. The dynamic

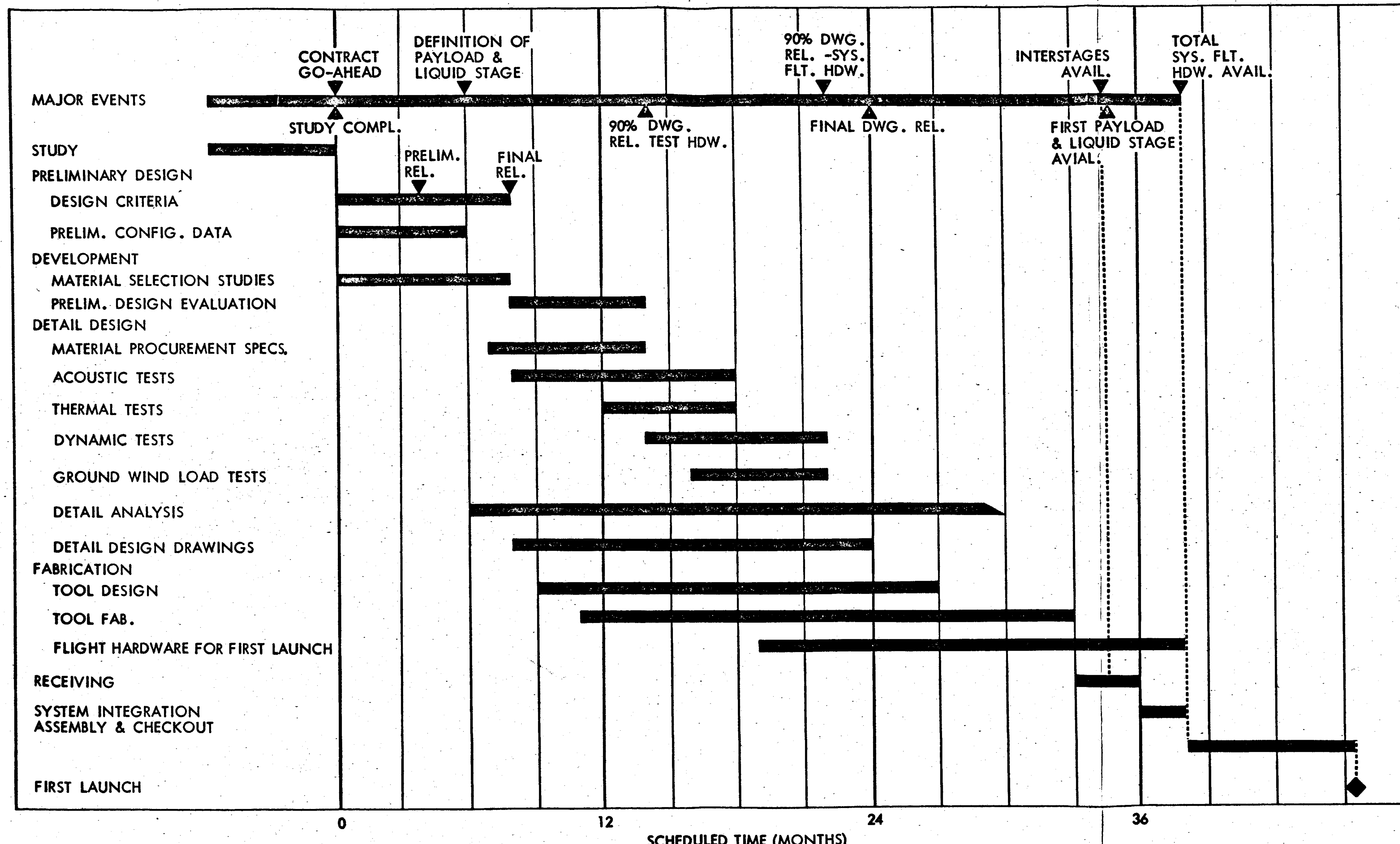


Fig. IV G-2 VEHICLE SCHEDULE
N-UC4

pressure at first stage burnout is 203 psf. The second stage thrust-to-weight ratio is 1.22 for this vehicle.

Trajectory parameters and their time history are shown in Figure IVG-3. A velocity-altitude history for the vehicle is shown in Figure IVG-4. This vehicle had the highest payload-to-launch weight, 0.038, of the six vehicles studied, due primarily to the high thrust of the liquid stage.

STRUCTURAL CHARACTERISTICS OF THE N-UC4 VEHICLE

Booster Motor Case Construction

The motor cases are fabricated from rolled and welded cylindrical sections of high-strength steel of a size compatible with existing heat-treat facilities. Forged rings of high-strength steel are welded to the ends of each section before heat treat. These rings are proportioned to permit an "as welded" joint to be made between the sections after heat treat, as shown in Figure IVA3-15. A continuity of the parent metal strength is therefore maintained.

The 1.4:1 semi-ellipsoidal end closures are high-strength steel assemblies machined to the proper size, shape and concentricity. Integral stub skirts are machined into the closure and cylindrical extensions are welded to the skirts to provide tie-ins for the base and interstage structures.

The closure bosses are machined forgings which are welded to the parent sections. The individual sections are heat treated to 200,000 psi ultimate tensile strength before case assembly.

Nozzle Construction

The convergent, or entrance-cap portions of the nozzles are formed of pressure-molded silica phenolic and covered with a heavy layer of silica-filled synthetic rubber insulation. The throat sections are assemblies of pressed graphite blocks backed with monolithic sections of molded silica-phenolic. The divergent

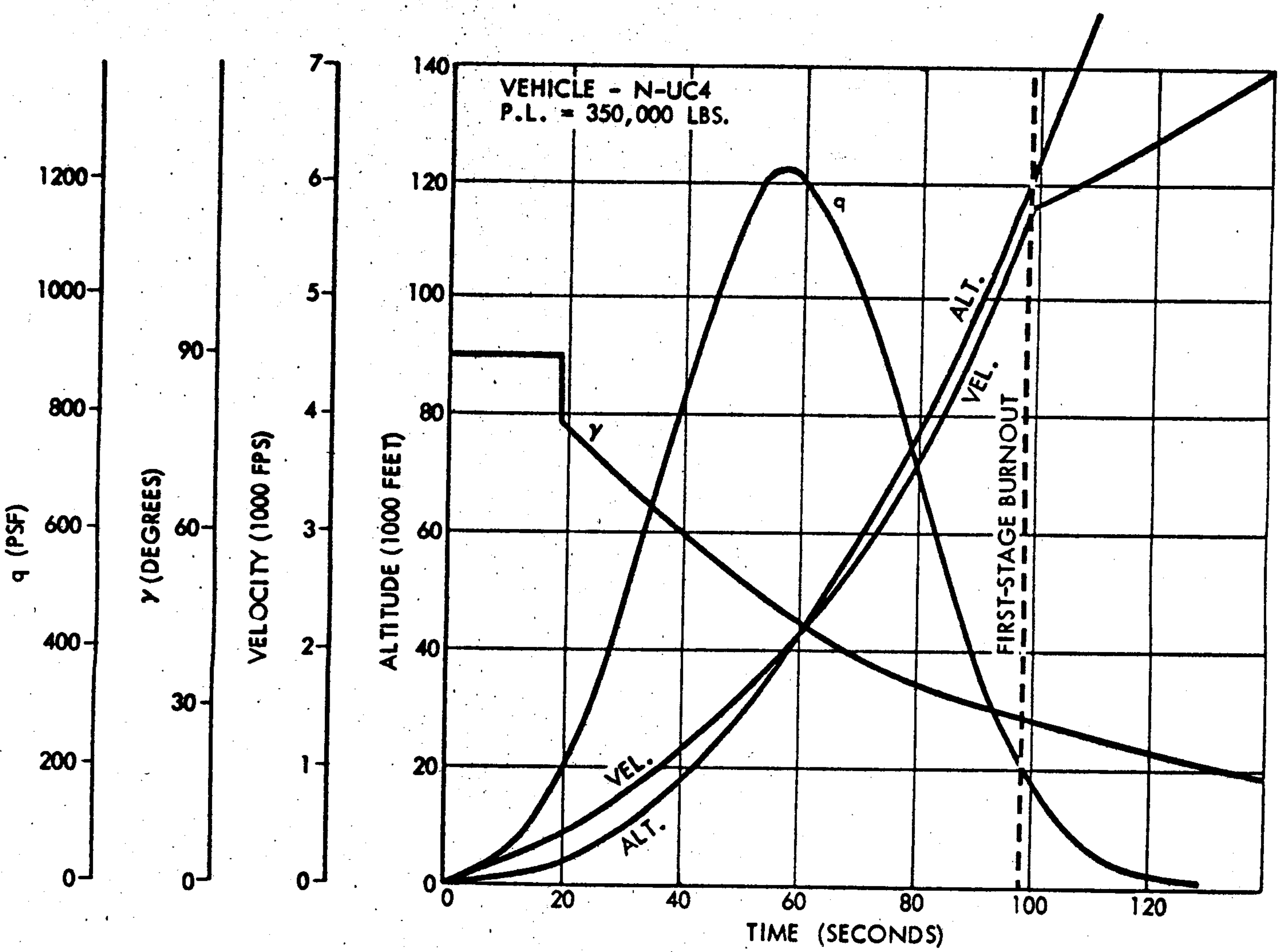


Fig. IV G-3 NASA SOLID STUDY
VEHICLE N-UC4

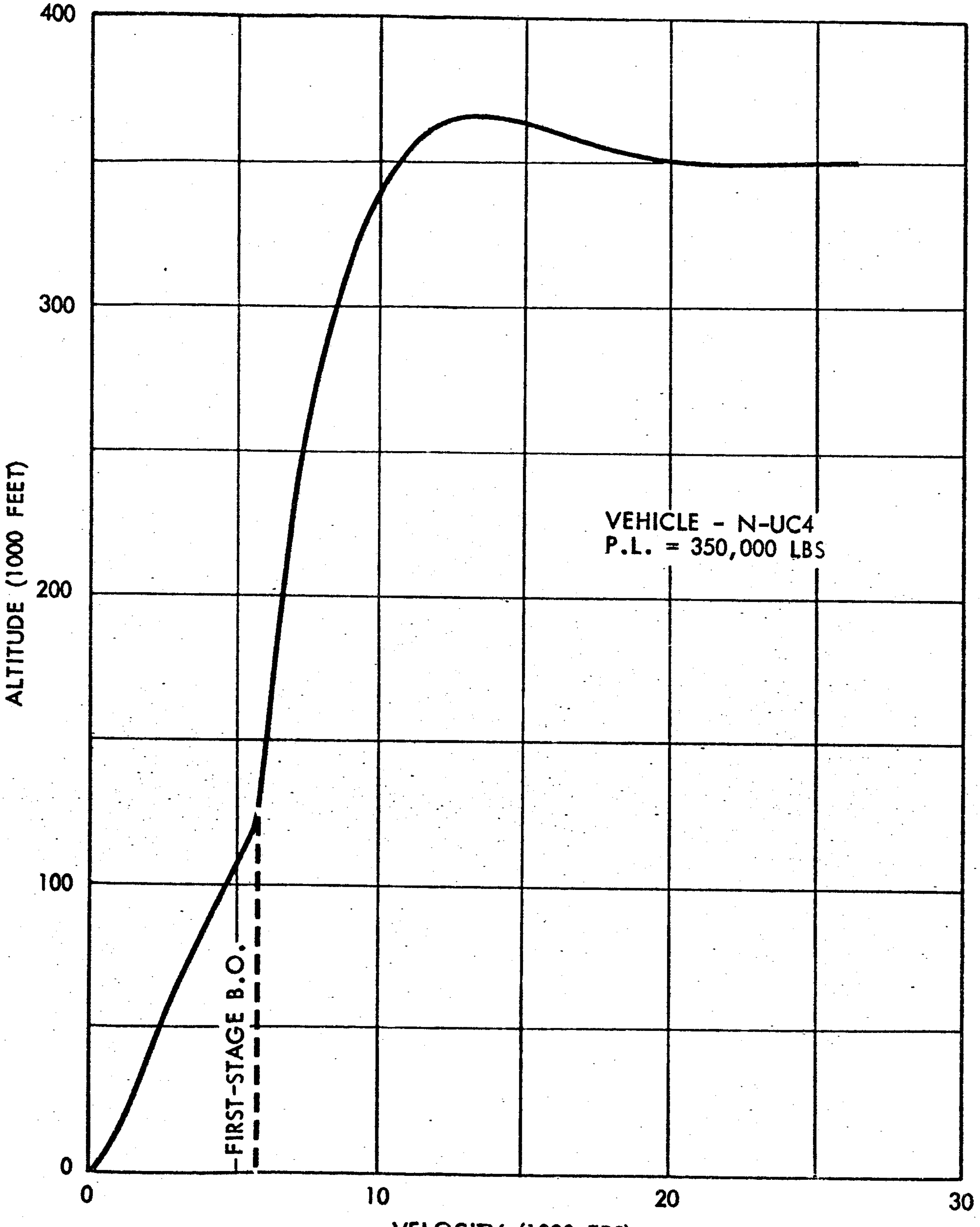


Fig. IV G-4 NASA SOLID STUDY
VEHICLE N-UC4

portions of the nozzles or exit cones are of oriented silica fiber-phenolic construction. The entire assemblies are encased in a steel outer shell which receives the structural loads.

Vehicle Base Structure

The vehicle launch support structure consists of four cylindrical sections of smooth aluminum alloy skin reinforced internally with circular aluminum "zee"-section-frames. These sections are attached to the booster motors at the aft skirt extensions. A channel-type frame at the base of each cylindrical section mates with the vehicle launcher pallet. This member also serves as a staging rocket support and thrust structure. The aluminum alloy material used throughout the base structure is heat treated to 70,000 psi ultimate tensile strength.

Interstage and Intrastage Structure

The aft interstage structure, located between the solid and liquid stages, is divided into two major parts; the case extensions, or barrel sections (see Figure IVA3-16) and the transition section (see Figure IVA3-17). Each barrel section consists of a smooth cylindrical outer skin of aluminum alloy reinforced at either end with a circular aluminum I-beam and stiffened with intermediate frames. The lower beam in each barrel section is attached to a corresponding skirt at the forward end of each booster motor.

Structural loads are carried from the barrel sections to the second-stage aft skirt by means of the interstage transition section. This structure consists of a geometrically contoured smooth aluminum outer skin reinforced internally with a series of frames and longitudinal stiffeners.

A central weldment of aluminum tubing to which the interstage barrel sections are attached, and a beam reinforced shear panel mounted between the outer extremities of each pair of barrel sections comprises the upper clustering structure. The clustering tie is completed by sliding-link attachments between the base structures of each motor which provide lateral restraint but permit relative longitudinal motion of the motors.

The forward interstage structure, which secures the second-stage tankage to the payload compartments, is of comparable construction to the aft interstage barrel sections. Vehicle guidance, telemetry and environmental control subsystems are mounted inside this structure on a framework of aluminum tubing.

Seventy-thousand psi ultimate tensile strength aluminum alloy is used throughout the interstage and intrastage structures.

Second-Stage Construction

The liquid propellants are carried in integral tankage constructed of aluminum alloy plate machined on the inner surface to produce waffle pattern ribs and rolled to the proper curvature. The rib height is tapered longitudinally to provide the necessary strength at any station with minimum structural weight. End bulkheads are 1.4:1 semi-ellipsoids of spun aluminum construction welded to the waffle structure.

A common hemispherical bulkhead of aluminum alloy honeycomb construction divides the tankage into two compartments, the liquid-oxygen located aft. Tank ullage pressures are 27 psia for the hydrogen and 31 psia for the oxygen. The hydrogen pipe lines bypass the oxygen compartment externally.

A trusswork of aluminum alloy tubing acts as support and thrust structure for the Y-1 engines.

TVC Tank Mounting

The TVC tanks consist of seven helium spheres suspended within the motor cluster above a cylindrical nitrogen tetroxide tank. The solid motor cases supply lateral support with the upper cluster structure carrying the axial load.

Fins

No fins are required on this vehicle.

First Mode Bending Frequency

The first mode bending frequency of this vehicle is approximately .8 cps. Methods of increasing first mode frequencies are discussed in Section IVA3D.

PROPULSION

First stage of the N-UC4 vehicle is made up of four 16-foot diameter unitized motors. This diameter was selected as the smallest practicable within conservative grain-port to nozzle-throat-area ratio limits for the grain configuration used.

Motor characteristics are summarized in Table IVG-1 and motor subsystems are described in Table IVG-2.

Because of the size of this vehicle and the time available for subsystems development, a reactive fluid thrust vector control system is specified. Nitrogen tetroxide was selected as the reference injectant on the basis of experimental programs already underway. A cold helium pressurization system is used.

FLIGHT CONTROL

The 350,000-pound payload Nova type vehicle has an overall fineness ratio of 10. Due to the high inertia in pitch and yaw, no fins are required to meet the stability criterion. A summary of the stability and control characteristics is presented in Table IVG-3. The maximum thrust vector angle required is 1.4 degrees and the total control system impulse is 1.0 percent of the main stage impulse.

The first-mode body-bending frequency is approximately .75 cps which is five times the minimum pitch control frequency. This is considered a marginal ratio and structural coupling problems may require a lower overall fineness

Table IVG-2

MOTOR SUBSYSTEMS FOR N-UC4 VEHICLE

350,000-Pound Payload Nova Type Booster

IGNITION SYSTEM

Type: Launch-Retained Pyrogen

THRUST VECTOR CONTROL SYSTEM

Type: N_2O_4 Injection	
Maximum Total Side Force Required, lb	236,000
Total Control Impulse Required, lb/sec	21,020,430
Maximum Total N_2O_4 Flow Rate, lb/sec	2,528
Total N_2O_4 Weight, lb	175,170
Total N_2O_4 Volume, ft^3	1,964
N_2O_4 Pressure, psia	1,600
Helium Blowdown Pressurization System	
Helium Pressure, psia	5,000
Total Helium Weight, lb	5,696
Total Helium Volume, ft^3	1,652

DESTRUCT Jet-Perforator

Table IVG-3

STABILITY AND CONTROL CHARACTERISTICS
VEHICLE N-UC4

350,000-Pound Payload Nova Type Booster

	Maximum q No Fins	Maximum q Fins	First Stage Burnout	Second Stage Startburn
Total fin size, ft^2	0	0	0	0
C_{N_α}, per degree	.05	-	.056	.045
C.P., fraction length aft of nose	.45	-	.48	.42
C.G., fraction length aft of nose	.66	-	.56	.70
q, psf	1200	-	203	135
$M\alpha$, $\frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	216	-	15.3	20
$M\delta$, $\frac{\text{ft-lb}}{\text{rad}} \times 10^{-6}$	1300	-	-	40.8
$M\alpha / M\delta$	.17	-	-	.49
I, slug - $ft^2 \times 10^{-6}$	1400	-	1085	840
$M\alpha / I$, sec^{-2}	.15	-	.014	.024
t_{2A}, time to double amplitude, sec	3.4	-	9.0	8.5
Maximum required thrust deflections				
For wind, degree	1.00			
For misalignment, degree	.43			
Total, degree	1.43			
Cant angle required, degree			5.25	

ratio, increased structural stiffening, or a lower pitch frequency through decreased vehicle instability.

WEIGHTS

A summary weight statement for vehicle N-UC4 is presented in Table IVG-4; detailed weight statements for the oxygen/hydrogen stage and the solid-propellant stage are also presented in Table IVG-4. These weights are based on criteria used for weight analysis purposes, as presented in Section IVA-5. (The primary criteria used for weight estimating purposes are summarized in Table IVA5-1 for the solid-propellant stages and in Table IVA5-5 for the oxygen/hydrogen stages.)

Table IVG-4

WEIGHT STATEMENT, VEHICLE N-UC4

Summary Weights

Payload (includes G&C Instrumentation)	(350,000)
Second-Stage Inert Weight at Burnout	(191,890)
Dry Weight	120,220
Reserve Propellant	32,510
PU Allowance	19,160
Gas Residuals	10,970
Trapped Propellant	9,030
VEHICLE WEIGHT AT SECOND-STAGE BURNOUT	(541,890)
Second-Stage Main-stage Propellant	(1,917,490)
Fuel, LH_2	319,580
Oxidizer, LO_2	1,597,910
VEHICLE WEIGHT AT SECOND-STAGE IGNITION	(2,459,380)
Second-Stage Items Expended During Separation/Start	(9,400)
Propellant for Chilldown/Start	4,500
Ullage Rocket Propellant	4,900
First-State Inert Weight at Burnout	(763,280)
Dry Weight	691,160
Sliver	58,190
Trapped Injectant, TVC System	10,430
Pressurant, TVC System	3,500
VEHICLE WEIGHT AT FIRST-STAGE BURNOUT	(3,232,060)
First-Stage Expected Propellant Consumption	(5,923,450)
Solid Propellant	5,819,200
Injectant, TVC System	104,250
VEHICLE WEIGHT AT LIFTOFF	(9,155,510)

Table IVG-4 (Cont.)

DETAILED WEIGHT STATEMENT
First Stage

Basic Motor:	(517,170)
Forward Bulkhead	25,600
Cylinder	375,390
Aft Bulkhead	36,560
Nozzle	46,840
Insulation and Liner, Forward Bulkhead	1,960
Insulation and Liner, Aft Bulkhead	10,120
Liner, Cylinder	8,680
Contingency	12,020
T.V.C. System: (Dry)	(73,620)
Tankage, Nitrogen Tetroxide	16,280
Tankage, Helium	47,990
Controls, Plumbing and Supports	9,350
Equipment:	(1,420)
Control Elements	20
Telemetry	530
Environmental Control Provisions	50
Power Supply and Electrical Network	740
Contingency	80
Structural Provisions:	(85,910)
Clustering Structure	52,380
Forward Interstage	14,400
Aft Skirts	6,280
Base Heat Protection	5,200
Separation Provisions	200
Contingency	7,450
Separation Rockets:	(13,040)
Propellant	9,120
Rocket Inerts	3,040
Attachment Fittings	880
Unusable Propellant and Residuals:	(72,120)
Sliver	58,190
Nitrogen Tetroxide Residual	10,430
Helium, T.V.C. System	3,500
STAGE WEIGHT AT BURNOUT	(763,280)
Expected Propellant Consumption:	(5,923,450)
Mainstage Propellant	5,819,200
Nitrogen Tetroxide	104,250
STAGE WEIGHT AT LIFTOFF	(6,686,730)
STAGE MASS FRACTION AT LIFTOFF	0.8860

Table IVG-4 (Cont.)

DETAILED WEIGHT STATEMENT
Second Stage

Structure:	(88,200)
Tankage	44,800
Antislosh and Vortex Provisions	2,620
Insulation, Tank	5,370
Forward Interstage	6,080
Aft Skirt	16,000
Thrust Structure	10,300
Base Heat Protection	1,670
Separation Provisions	160
Contingency	1,200
Propulsion System and Accessories:	(29,890)
Engine Package (Dry)	19,650
Propellant Distribution System	1,750
Pressurization Equipment	500
Fill and Drain System	170
Vent System	110
Propellant Loading/Utilization System	90
T.V.C. System	1,260
Staging Rockets Group	5,460
Contingency	900
Equipment:	(2,130)
Control Elements	20
Telemetry	700
Environmental Control Provisions	50
Power Supply and Electrical Network	1,095
Range Safety and Destruct Systems	70
Contingency	195
Unusable Propellant and Gas Residuals:	(20,000)
Propellant in Engine Package	1,350
Propellant in Lines	7,300
Gaseous Hydrogen	2,320
Gaseous Oxygen	7,550
Helium Slugs	500
Contingency	980
Usable Propellant Residuals:	(51,670)
Propellant Utilization Allowance	19,160
Reserve Propellant	32,510
STAGE WEIGHT AT BURNOUT	(191,890)
Mainstage Propellant:	(1,917,490)
STAGE WEIGHT AT IGNITION	(2,109,380)

Table IVG-4 (Cont.)

Items Expended Prior to Ignition:	(9,400)
Ullage Rocket Propellant	4,900
Propellant for Chilldown/Start	4,500
STAGE WEIGHT PRIOR TO IGNITION	(2,118,780)
STAGE MASS FRACTION AT IGNITION	0.9090

V. SUPPORT SYSTEMS

A. CONCEPTS

1. BACKGROUND

The initial vehicle configurations were analyzed to determine the requirements for the ground support system. It was immediately evident that: the size and weight of the total vehicle and components; the quantities of propellant; the numbers of vehicles required by the launch rate programs; and the present capability of the solid rocket industry would have the most influence on a concept of the ground support system.

The pattern of the industry was examined to determine to what extent the present know-how and facilities could be utilized to provide, primarily, the solid propellant motors. The industry was found to be oriented toward the segmented design with present facilities inadequate for the requirements of these programs. However, capacity could be developed to produce solid motor segments and comparatively small unitized motors within the desired time period. New or modified facilities would be required for welding and heat treating even the recommended small size segments, and new techniques and facilities would be necessary for the unitized cases. There are existing facilities for mixing propellant, and for casting and curing segments of solid propellant motors, only for sizes and quantities much less than suggested by this study. Even if advantage were to be taken of this capability, additional new facilities of considerable capacity and size would be required.

It was concluded that the present industry could be supplemented to provide for an early start on an R&D program for the segmented designs, but that considerable new facilities would be necessary for both R&D and production programs.

The location pattern of present sources of motor cases (primarily in the Northeastern states), the solid motors (mostly in the Western states), and liquid stage motors (in the central Gulf states) was analyzed to determine the limitations imposed by transportation regulations. From the study it was determined that: air transport could be ruled out because of size and weight restrictions and cost; highway transport imposed severe restrictions on weight and required special permits, handling and routing for the sizes required; railroad transport could handle larger weights but was limited by size of bridges and tunnels, particularly, in the Eastern half of the country; and water transport was suitable for both large weights and sizes of cases and motors. There is not a simple solution. By pushing all limits, the transportation pattern at best would be composed of long distances, combinations of modes, special handling, large amounts of equipment, special routes, and numerous transfer terminals. Also, the hazards of transporting explosives, physical damage to the motor case or grain, and environmental change are items of concern in long distance transportation and contribute to high costs of transport and insurance.

It was concluded that transportation from present sources to Cape Canaveral is feasible for an initial R&D effort, but since new facilities are required, they should be located within a radius of a few miles from the launch complex and on a navigable waterway. Also, facilities for propellant preparation and mixing must be located adjacent to motor casting and curing at any selected location.

It is mandatory that all of the larger unitized solid motors and liquid stage motors be transported by water because of weight and size. However, the very large weight of the solid motors also makes it desirable to minimize the transport distance so that heavy capacity lifting equipment would be needed only at the single destination. Liquid stage motors, solid motor cases, nozzles, airframes, subassemblies and components can be procured and shipped from present scattered sources and do not necessarily need to be manufactured adjacent to the assembly and launch complexes.

The desirability of integrating the solid motor production closely with the assembly and launch complexes was equally valid for segmented and unitized motors.

The concept of transporting heavy motors up to 1,500,000 pounds by water was extended to provide even greater advantage within the area of an integrated base. The cost per mile of canal was estimated to be $250,000 as compared with an estimate of $1,000,000 per mile for a rail system, to support a vehicle weight of 9,000,000 pounds. The rail system could run to $4,000,000 per mile dependent on the concentration of load on the wheel tracks. The simple welded steel construction of standard barges with no mechanisms was considered desirable by comparison with wheeled vehicles and the associated problems of level weight concentration, bearings, shock absorption and maintenance. The topography of a potential site adjacent to Cape Canaveral was examined in aerial photographs along with detailed geological information of the area to determine adequacy of the terrain to support the required weights. This examination indicated, that for the separation distances, from 1000 to 3000 feet required by explosive hazards and from 6000 to 20,000 feet for acoustical hazards of the large solid-propellant motors, considerable difficulty would be encountered with transportation facilities constructed above ground and transport vehicles would be more complex. These comparisons all favored the use of a waterborne transportation system on the base. Consequently the apparent advantages were evaluated for all operations occurring on the base. The waterborne system was used for all transportation of motors, structural components, payload, and completely assembled vehicles.

Concurrently with the development of an integrated base and waterborne transportation system, studies were conducted to reduce the number of assembly-launch pads required by the high launch rate programs and the longer operational time required on the pads. For the 3-UC4 vehicle the minimum pad time required, including assembly and launch, amounts to two months, which means 2, 8, and 20 pads, respectively for launch rates of 1, 4, and 10 per month. By separating the vehicle assembly from the launch site the number of launch pads on the firing line was reduced 75 percent to 1, 2, and 5 pads for the same vehicle and launch rates. However, less critical locations back from the firing line were required for assembly sites, but these did not require as much surrounding land to meet quantity-distance requirements due to less propellant aboard the vehicle. For the launch rate of 10 per month for the 3-UC4 or 3-SC4 vehicles this meant a reduction of valuable waterfront acreage up to 35 percent and a reduction in total base acreage required up to 58 percent. Bases have been laid out for all vehicles to support all launch rates on the basis of required distances for safety from explosion and acoustical hazards. This study resulted in a pullback from the launch site of all operations except countdown and launch, and the general separation of major operations which were to be conducted at special isolated facilities.

The decision to use this assembly-line concept resulted in several advantages. The different units of flow time in an overall operational plan and production rates for each vehicle configuration could easily be accommodated by adding facilities units and combining or separating major operations. Such flexibility would permit growth in numbers of vehicles due to increased launch rates, and growth from a single configuration to larger configurations or even several configurations at the same time, without obsolescence of facilities, with gradual buildup as needed, and with a minimum of overdesign. This concept was exceptionally complementary to the integrated base and the waterborne transportation concepts.

Again, the assembly line concept was valid for either the segmented or unitized solid-propellant motors. In fact, the combination of assembly line and waterborne techniques on an integrated base offers many advantages over land based systems for all-liquid, and all-solid vehicles as well as the solid-liquid configurations. Also, these techniques could be advantageously used in the manufacture of all large heavy components such as liquid stage motors, nozzles and payloads.

The scope of this study did not permit the development of a comparable base concept using a completely land based transportation system.

2. OPERATIONAL CONCEPT

There are two basic operational concepts due mainly to the differences in production between the segmented and unitized configurations of the solid propellant motors. For design and quantity production the cases for solid motors would be formed, welded, and heat-treated by present manufacturers who would have to modify and expand present facilities. These cases would be transported by truck or rail from source to motor manufacturers. The motor segments for the 1-S1 and the 3-SC4 would be cast, cured, inspected and tested by present manufacturers at present locations for R&D and low launch rate programs. Capacity for preparation and mixing of propellant, as well as the cleaning, insulating and preparation of cases, would have to be expanded at each motor production site in proportion to the production quantities required. The unitized solid motors of the 3-UC4 could be manufactured in this same manner. All completed segments and the 3-UC4 unitized motors would be shipped by rail to New Orleans and then transferred to a sea-going barge for movement to Cape Canaveral.

The nozzles, subsystems, stage structure, and intrastage structure would be obtained from present manufacturers with no requirements for extensive facilities modification or expansion. The second-stage liquid fuel tanks and engines are assumed to be available at New Orleans and to be shipped by barge to Cape Canaveral. It is also assumed that the payload capsule and propulsion tanks would be furnished and available at Cape Canaveral by barge.

The shipment of segments, small unitized motors, and all other vehicle components to the base by water would eliminate all motor production capability at the base. However, such capability could be built in the vicinity of the assembly and launch complexes at Cape Canaveral, either as an integrated plant or by several separate contractors located nearby. The reduced long distance transportation would make this location desirable for the higher launch rates.

In consideration of the weight and large size of unitized motors for the 4-UC4 and N-UC4 configurations, motor production would be conducted at the base location and integrated with the assembly and launch complexes. The fabricated motor cases would be received by rail or barge. The production would be backed up by a case preparation plant and a solid-propellant preparation and mixing plant. The production line would include the major operations of positioning the motor case, casting the propellant, curing the propellant, inspection of the motor, storage, and static test during the R&D program, all at stations widely separated for hazard protection. Individual motors in vertical position on separate barges would be moved through this line in canals, moved by sea mules. In this manner, motors would be moved along the canal to a land based test stand for static test during an engine development program.

All components for any configuration, segmented or unitized, would be available at common inspection and test integration facilities where operations would be conducted in preparation for assembly. Structural components and subsystems would be assembled into major subassemblies.

At this point all components, and either motor segments or unitized motors, would be available at the final assembly area. The first stage would be assembled at one site and the second stage and payload added to the first stage at a second site. For most cases final vehicle checkout would be conducted at this second site. In a few cases, the assembled vehicle is moved to a special checkout site. In all cases the completely assembled and checked out vehicle is moved to a launch site for the final liquid fueling and countdown.

The vehicle is assembled on a movable structural steel pad which is set rigidly on a piling structure at each operational site. The pad with each progressive stage of assembly and checkout is moved from site to site by means of barges which lift the pad from the foundation and float it along canals.

The vehicles using segmented motors could be assembled on a typical dryland launch pad for initial R&D or low launch-rate programs, if adequate cranes were available and modifications of the pad could be made.

B. MANUFACTURING PLAN

1. GENERAL CONSIDERATIONS

The development of a manufacturing plan involves the consideration of many factors: manufacturing philosophy; materials used; fabrication techniques; capabilities available; facilities available; manufacturing research potentials, and such things as geographical locations.

MANUFACTURING PHILOSOPHY

The urgency of this program suggests that, whenever possible, existing techniques be used. As mentioned in Section VI, maximum utilization will be made of existing facilities. The manufacturing plans presented here will be based on known techniques available now. Potential improvements in processes being developed through research and development programs should be incorporated as rapidly as possible.

MATERIALS

Engine case materials were investigated from the manufacturing viewpoint to determine which of the low-alloy, high-strength steels would provide the greatest potential:

Tricent	Ladish D6A
4130	Ladish D9
4330M	H-11

The materials were evaluated,according to their ability to be machined, welded, formed, and the heat-treat method required. Table V-1 indicates the complexity factor associated with each steel according to the parameters evaluated. This chart selects 4330M as the preferred material. It represents the material least difficult to fabricate. Although this method of evaluation indicates a preference, it should not be construed to mean that the remaining materials are inadequate. Other materials could be selected on the basis of available capabilities and facilities. For example, H-11, an air quench material, could be selected because it

	TRICENT (1)			4130 (2)			4330 M (3)			LADISH (4) D6A			LADISH (5) D9			HACCOMB 218 VASCO JET 1000 H-11 DIE STL. (6)			
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	PROCESS
HEAT TREATMENT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	H. T. or Annealing in Air
	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	Quenching.
	2	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	Aging, Tempering,
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Stress Relieve
WELDING	2	1	1				1	1	1	3	2	1	3	2	1	3	2	1	TIG
							2	1	1	3	2	1	3	2	1				MIG
							.7	.3	.3	1	.7	.3	1	.7	.3				Submerged Arc
MACHINING	1.8	1.8	1.8				1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	Surfacing
	1.8	1.8	1.7				1.8	1.8	1.7	1.8	1.8	1.7	1.8	1.8	1.7	1.8	1.8	1.7	Pocketing
	2.1	2.1	2.0				2.1	2.1	2.0	2.1	2.1	2.0	2.1	2.1	2.0	2.1	2.1	2.0	Hole Production
	1.8	1.8	1.7				1.8	1.8	1.7	1.8	1.8	1.7	1.8	1.8	1.7	1.8	1.8	1.7	Trimming
	1.9	1.9	1.9				1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	Threading
FORMING	1.5	1.5	1.5				1	1	1	2	2	2	1	1	1	1	1	1	Press
	3.7	3.7	3.7				3.7	3.7	3.5	8	8	8	6.5	6.5	6.5	3.9	3.9	3.9	Spinning
	3	3	3				2	2	2	4	4	4	3.8	3.8	3.8	2	2	2	Roll
	2	2	1.5				2	2	2	6	6	4	5	5	4	.9	.9	.9	Explosive
	2.5	2.5	2.5				1.5	1.5	1.5	4	4	4	3.7	3.7	3.7	2	2	2	Hydro

Increased Complexity Indicated
by Increasing Numbers

LEGEND

A - Boeing Capabilities
B - Industry Capabilities
C - Boeing Capability in five years

Table V-1

would not require new heat-treat facilities; whereas a liquid quench material would require new heat-treat facilities. The chart does define the difficult fabrication techniques for any steel that may be selected.

FORMING METHOD

In forming the cylindrical segments and the forward and aft closures of the tank body, six processes were investigated.

1) Shear forming of large diameter cases and closures would eliminate much of the welding required and increase the reliability potential. This process has been used successfully on small diameter cases but an advance in the state of the art, through a manufacturing research program, would be essential before satisfactory use of this process for large diameter cases can be accomplished.
2) Hot spinning dished heads is within the state of the art. Preliminary investigation indicates that with some development, ellipsoidal or hemispherical heads can also be manufactured using this process.
3) Explosive forming of large diameter closures may be accomplished economically after some research and development. The disadvantages stem from the handling and sealing problems and the low production rate inherent in this process.
4) Press forming gored segments, which in turn are trimmed and welded together to form a closure, is well within the state of the art. The amount of welding required, the tooling required, and the reliability confidence level are disadvantages.
5) Roll forming of the cylindrical portions of the tank body is an existing capability. After rolling, the cylinder is closed with a longitudinal weld. This process is conventional and has proven to be the best present method of developing a large cylindrical shape.

   It is recommended that roll forming be used initially for manufacture of the cylindrical parts of the tank body. A research and development program to develop the potential use of shear forming to supersede roll forming should be initiated.

6) Press forging of the end closures is an available technique in the 13.3-foot diameter. Additional press capacity will be required for larger diameters. To form the ellipsoidal shaped closures, press forging has been selected for immediate use on the smaller cases.

MACHINING

Machining operations (turning, facing, boring, drilling, reaming, etc.) associated with these large diameter cases can be accomplished with conventional facilities available in the industry.

HEAT TREAT

The material selected for these solid-fuel cases will determine the heat treat process used. The variable occurs in the quench methods available. The material may be quenched by dipping into water, oil, or in a mar-tempering solution. The material may also be sprayed with any one of these liquids or it may be allowed to cool in the open air (draft free).

Quenching by immersing in a liquid imposes a severe strain in the material because the case reduces in diameter entering the liquid. The sharp working of the metal can be avoided by using the spray technique. However, the quantities of clean water or hot oil required will present storage, filtering, and pumping problems. The air hardening process presents the fewest problems and is considered the most readily available.

The Ardeform* hardening process is a good potential that warrants further study. In this process the hardness is induced by working the metal with rapidly expanding gases at cryogenic temperatures.

* Ardeform—Trademark of Arde-Portland, Inc., Paramus, N.J.

WELDING

Welding operations are critical. The reliability requirements are high. The welds must be top grade. Existing programs are using a TIG weld on the first pass for optimum penetration followed by MIG or submerged arc filler passes. Preheat and postheat temperatures must be maintained within narrow limits. Cleanliness approaching laboratory standards is desirable extending into the weld rod manufacturing processes and the protection of prepared edges by copper plating. A continuous, concurrent manufacturing research program to advance the state of the art is recommended.

HYDROSTATIC TESTING

A hydrostatic pressure test is required to determine whether the tanks will withstand the internal pressure produced when the motor is burning.

The test facility would be located in or close to the production area. An economic trade study would be made to determine the test stand configuration, an underground silo, an above ground vertical tower-type operation or a horizontal saddle supported test stand. Pressure would be developed by pumping the case full of water or oil. Portable equipment should be available for minor repairs.

This operation is not expected to present any difficult problems except for size. Filling the large unitized cases could impose a time penalty. Adequate storage and pumping capacity are essential.

2. COMPONENT FABRICATION

GENERAL

A fabrication plan is outlined and discussed for the case, nozzle and the interstage structures for the various vehicles. A process plan for propellant manufacture is also defined.

CASE FABRICATION

Segmented Cases (1-S1, 3-SC4)

The 1-S1 case is manufactured in four major assemblies, the forward closure, the aft closure and two center segments. These units are interchangeable and can be shipped individually to the propellant manufacturer.

The manufacturing procedures are similar for some components even though they may differ somewhat in detail. These components are: 1) the mechanical joint ring forgings, 2) the cylindrical sections (body and skirt), 3) the weld ring forgings, and 4) the aft and forward closure forgings. Figure V-1 shows these components.

The mechanical joint ring forgings are purchased in the annealed condition and machined to rough size allowing excess for cleanup after heat distortion in the succeeding processes. One edge is machined to the correct size and configuration for welding.

The cylindrical sections (three different lengths) are formed from rolled skins welded longitudinally. The ends of this section are trimmed square with the centerline of the roll and the edges prepared for welding. A sizing operation may be needed to obtain exact end diameters. Appendix 2, Figure AV-1 is a flow chart of these operations.

The weld ring forgings make up the outer half of the end closure assemblies. These forgings are received in the annealed condition and are machined into the transition from the cylindrical section to the elliptical header and to the skirt. The edges are prepared for welding.

The forward closure forging forms the dished end of the elliptical header. The periphery is prepared for welding. A top center hole is provided. The thick boss around this hole is machined for a ignitor attach ring or a cover plate.

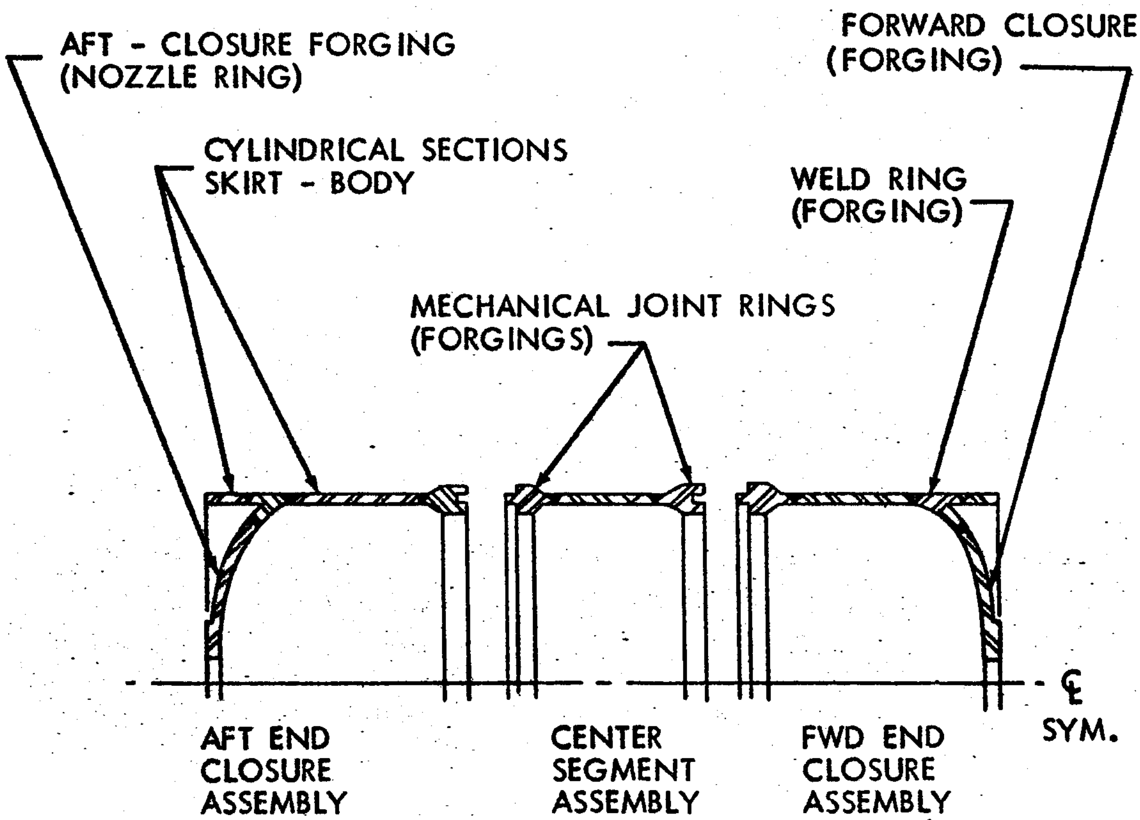

AFT - CLOSURE FORGING
(NOZZLE RING)
CYLINDRICAL SECTIONS
SKIRT - BODY
FORWARD CLOSURE
(FORGING)
WELD RING
(FORGING)
MECHANICAL JOINT RINGS
(FORGINGS)
℄
SYM.
AFT END
CLOSURE
ASSEMBLY
CENTER
SEGMENT
ASSEMBLY
FWD END
CLOSURE
ASSEMBLY

Fig. V-1 3-SC4

The aft closure forging is similar to the forward closure forging except that a larger center hole has been provided. The heavily bossed edge of this hole is machined for the nozzle attachment.

The assembly of these components into the major assemblies is accomplished in fixtures providing completely automated circumferential welding.

Each of the assemblies will then be oven stress relieved to remove the stresses developed during the welding procedures. Another machine operation is required to obtain "before heat-treat dimensions." Each assembly is heat treated to obtain the ultimate material strength. A final machine operation is required on the mechanical joint to provide interchangeability. The assemblies are shipped to the propellant manufacturer. Appendix 2, Figure AV-2 shows these operations.

The units are received in the inert-materials preparation area. Initially the assemblies are thoroughly checked to determine dimensional accuracy and configuration.

The internal surfaces are sand blasted to provide fresh, noncontaminated areas. A vapor degreasing prepares the section for insulation and liner application.

Insulation is applied by hand in the top center of the forward end closure, in the nozzle attach areas of the aft end closure, and in the area of the mechanical joints. These points are most affected by the heat. The liner material, which will vary depending on the nature of the propellant and the manufacturer, is applied to the internal surfaces and over the insulation by a rotating spray or sling. Oven curing is required.

The case sections are sent to the casting and curing pit area. Sections this size can be easily handled by the vacuum cast method. A large vacuum bell is used to remove the atmosphere and maintain the temperature during the propellant casting and curing operation. The section will remain in the pit during the curing cycle.

The case segments are then transported to the vehicle assembly area. Transportation problems are discussed under Operational Concept.

Unitized Cases (3-UC4, 4-UC4, N-UC4)

The unitized motor cases for the 3-UC4 vehicle are manufactured in three assemblies: the forward end closure, the aft end closure, and the center section. Each of the end closures is composed of an end closure forging, a weld ring forging to provide the transition from the header to the side-wall, a cylindrical skirt, a cylindrical body section, and a weld joint forging.

These parts are rough- or finish-machined as required and assembled in fixtures by automated circumferential welds.

The center section is fabricated from two joint forgings and a cylindrical body section, machined, and joined with circumferential welds. The first basic difference in the fabrication of this unitized case, from a segmented case, is in the machining of the weld joint forgings versus machining the mechanical joint forging. Figure IVA3-15 illustrates a version of this variation. After stress relieving in an oven, the weld joint forging is machined to preheat-treat dimensions. A final machine operation follows the heat treat.

Case assembly is the second basic difference in the fabrication procedures. The three major assemblies are fixtured for alignment and joined by automated circumferential welds. These final welds are not heat treated. Extra thickness has been allowed in machining the weld joint forgings to compensate for the reduced material strength. A localized stress relief will remove the weld stresses.

A fabrication plan for the 4-UC4 vehicle would utilize the same technologies. The major difference is the magnitude of the task. Although the case is the same diameter, it is approximately three times as long. It would require slightly longer sections and three center sections instead of one. Each center section has two cylindrical sections instead of one. The case material and size of the available heat-treat facility are the factors that limit the size of a heat treatable case section. Fabrication of the N-UC4 motor cases would follow the same pattern.

NOZZLE FABRICATION

The basic steel structure of the nozzle consists of two sheet-metal cones and one machined forging (Figure V-2). The base ring and the exit cone are roll formed to shape. The ends are then trimmed square with the centerline and the edges prepared for weld. The transition ring is received as an annealed forging, and is rough machined (finish machined in some dimensions).

These components are then welded together by two circumferential welds to form the basic nozzle shape. Four longitudinal steel gussets are welded to the assembly to provide rigidity in the throat area. The entire steel structure is stress relieved to remove the stresses built up by welding. Dimensional accuracy is obtained by a finish machine operation to ensure correct fit-up of the fiberglass inserts and interchangeability at the nozzle attach juncture.

The internal fiberglass components are fabricated by machine wrapping or hand wrapping tape on a mandrel. These layups are then pressure molded and machined to size. The fiberglass components are bonded to the internal surfaces of the steel structure. Carefully machined graphite blocks are inserted into the convergent conical throat section. The blocks are keyed together. The fit is critical. Appendix 2, Figure AV-3 defines the sequence of operations.

The fabrication techniques required for the various vehicle nozzles will vary only as to component size.

INTERSTAGE FABRICATION

The structure between the solid-fueled first step and the liquid-fueled second step of the 1-S1 vehicle is a cylindrical extension of both cases. It is composed of

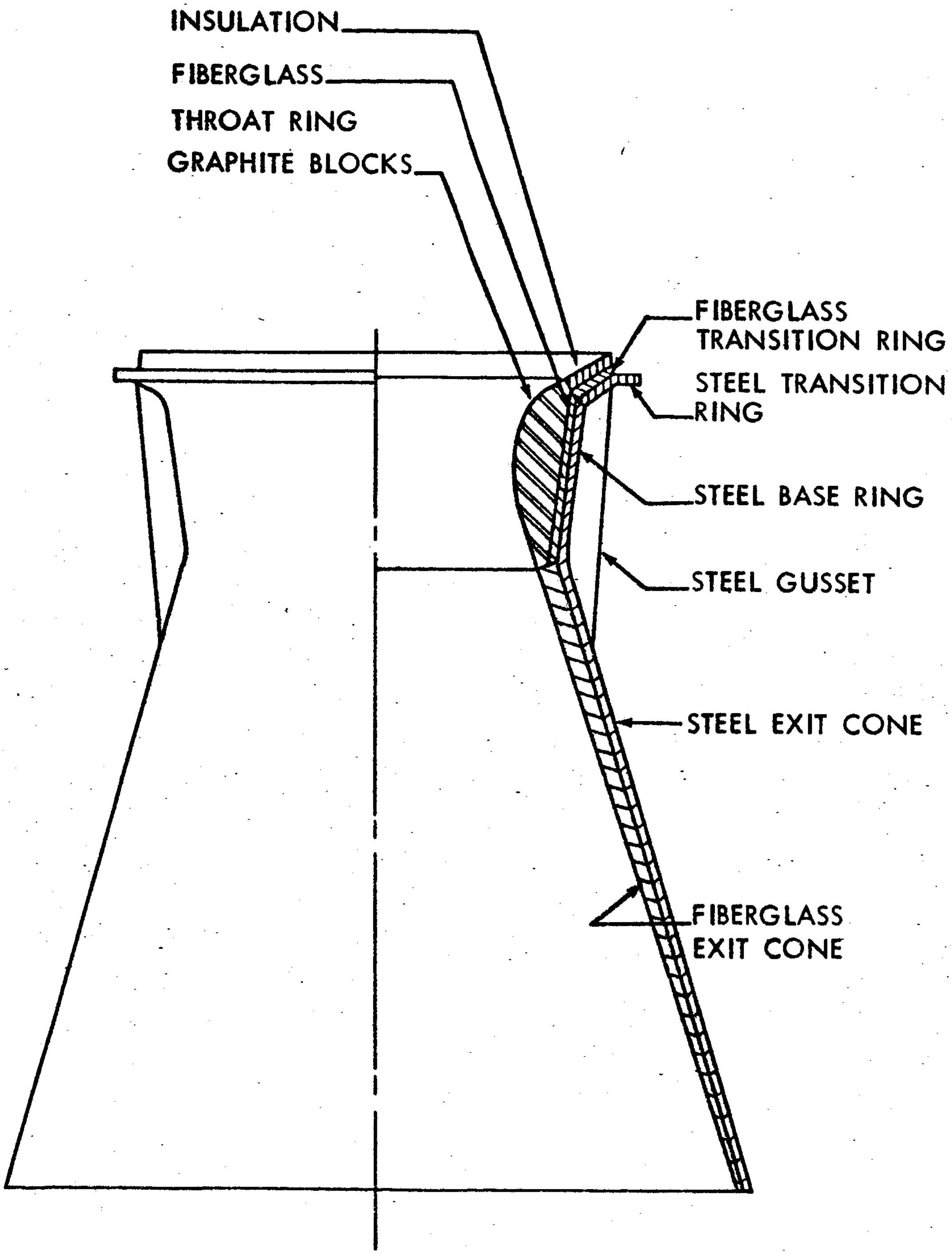


Fig. V-2 TYPICAL NOZZLE

corrugated skin, circumferential and longitudinal stiffeners, assembled and riveted together by the techniques of standard airplane construction.

The structure between the liquid second step and the payload is of similar construction with an ablative coating.

These interstage structures can be fabricated into logical subassemblies and shipped to the near-site assembly complex for final assembly and test.

The interstage structure between the first and second stage of a clustered vehicle is composed of cylindrical skirt extensions for each of the four cases and a fairing section that provides the transitions from these extensions to the liquid tank diameter (Figures IVA3-16 and IVA3-17).

These components are also basically standard aircraft type construction, aluminum skins, stringers and beams, drilled and riveted assemblies, fabricated and assembled by techniques familiar to the industry.

PROPELLANT MANUFACTURE

The R&D phase of propellant manufacture may be conducted in existing facilities. The production program would be handled at a new, near-launch-site plant. A description of these facilities is in Section VI, Facilities.

Materials

For the production quantities defined by the Boeing vehicle configuration and the NASA launch rate program "A," raw material procurement problems will be minimal. Ammonium perchlorate, the material in shortest supply, can be made available within the time span.

Table V-2 converts the propellant requirements for each vehicle into monthly and annual totals.

Table V-2

PROPELLANT REQUIREMENTS AT LAUNCH RATE"A" (NASA CHART)

Propellant Requirements	1-S1	3-SC4	3-UC4	4-UC4	4UC6L	N-UC4
Single Motor	571,890	406,747	398,655	1,124,452		1,454,800
Per Month						
1st Year 1 flight in 2 months	285,945	813,494	797,315	2,248,905		1 flight in 6 months
2nd Year 1 flight in 1.3 months	428,917	1,220,241	1,175,872	3,373,357		1 flight in 3 months
3rd Year and on 1 flight per month	571,890	1,626,988	1,594,630	4,497,810	5,023,420 one flight	5,819,200 - 1 flight every 2 months
Per Year						
1st Year—6 flights	3,431,340	9,761,928	9,567,780	26,987,360		11,638,400 - 2 flights
2nd Year—9 flights	5,147,010	14,642,892	14,351,670	40,481,040		23,276,800 - 4 flights
3rd Year and after 12 flights	6,862,680	19,523,856	19,135,560	53,974,720		34,879,200 - 6 flights

Methods

Mixing propellant is basically a fixed process. Each manufacturer follows his own procedures specifically tailored to his particular product and to his past experience. For instance, the batch mix process may use a horizontal or a vertical mixer operating with or without a vacuum in the mixing chamber. The continuous mix propellant plant is an extension of this process. All operations are fully automated. The mechanism selects correct proportions of the various ingredients, mixes them and delivers a high quality product in an uninterrupted flow. Future development will provide improved quality control and automated delivery over longer distances.

MANUFACTURING SCHEDULE

The component manufacturing schedule is based on program concurrency. The programs for vehicle design; the production plan, design and construction of tools; test motor fabrication; and actual flight hardware will all be running parallel to each other.

The hardware to be manufactured for the initial tests will consist of basic nozzles and unlined motor cases ready for processing by the propellant manufacturer. These components will be manufactured under R&D conditions prior to completion of the production tools. The thrust vectoring system will be built on a similar basis and integrated into the program. As the test program moves along, the quality of these units will improve as more tools become available, until nineteen to thirty months after start date, complete flight-quality motors will be available. The intrastage and interstage structure will be built and tested concurrently and will be available for vehicle flight tests approximately 3 years after time zero.

The preliminary design and preliminary production planning will begin simultaneously. The design of tools will begin prior to completion of the preliminary design. The fabrication of these tools will begin prior to completion of the tool designs. The fabrication of the test motor will begin prior to the release of a test motor design. These advance start dates are predicated on adequate communications enabling the production groups to be fully aware of engineering design concepts and development.

Detailed schedules are shown in Figures V-3 and V-4 for the 1-S1 and the N-UC4 vehicles.

SUBSYSTEMS

The thrust vector control system hardware is the major manufacturing task in this area. This system on the 1-S1 vehicle consists of sixteen interconnected spherical tanks, eight for Freon and eight for helium, manifolded to inject Freon into the nozzle. The Freon tanks, 42 inches in diameter, are fabricated of 3/8-inch-thick titanium. The helium pressure tanks, also 42 inches in diameter, are fabricated of 13/16-inch-thick titanium. All sixteen tanks are annealed to 120,000 psi. Some difficulty may be experienced in forming the thicker tanks. All other manufacturing tasks are within the state of the art.

The thrust vector control system for the clustered vehicles consists of a helium/hydrazine generating system and a large Freon tank. The piping and valving are standard production items. The titanium tank manufacturing task, supplemented with an in-house manufacturing research program, does not present any insurmountable fabrication problems.

The fabrication of the aft skirt and the fins will require considerable manhours and floor space. However, the manufacturing techniques involved are familiar to the aircraft industry. No foreseeable problems are evident.

3. VEHICLE ASSEMBLY AND TEST

The vehicle assembly operations will be conducted, as previously noted, in an assembly complex near the launch site. The sequence of operations is depicted in the functional flow charts (Appendix 2, Figures AV-4, -5, and -6). Flow time charts (Appendix 2, Figures AV-7 through -10) are also provided to define the time allotted for each operation and the interrelation of these operational flow times.

The operations to be conducted at the assembly complex can be categorized in this manner:

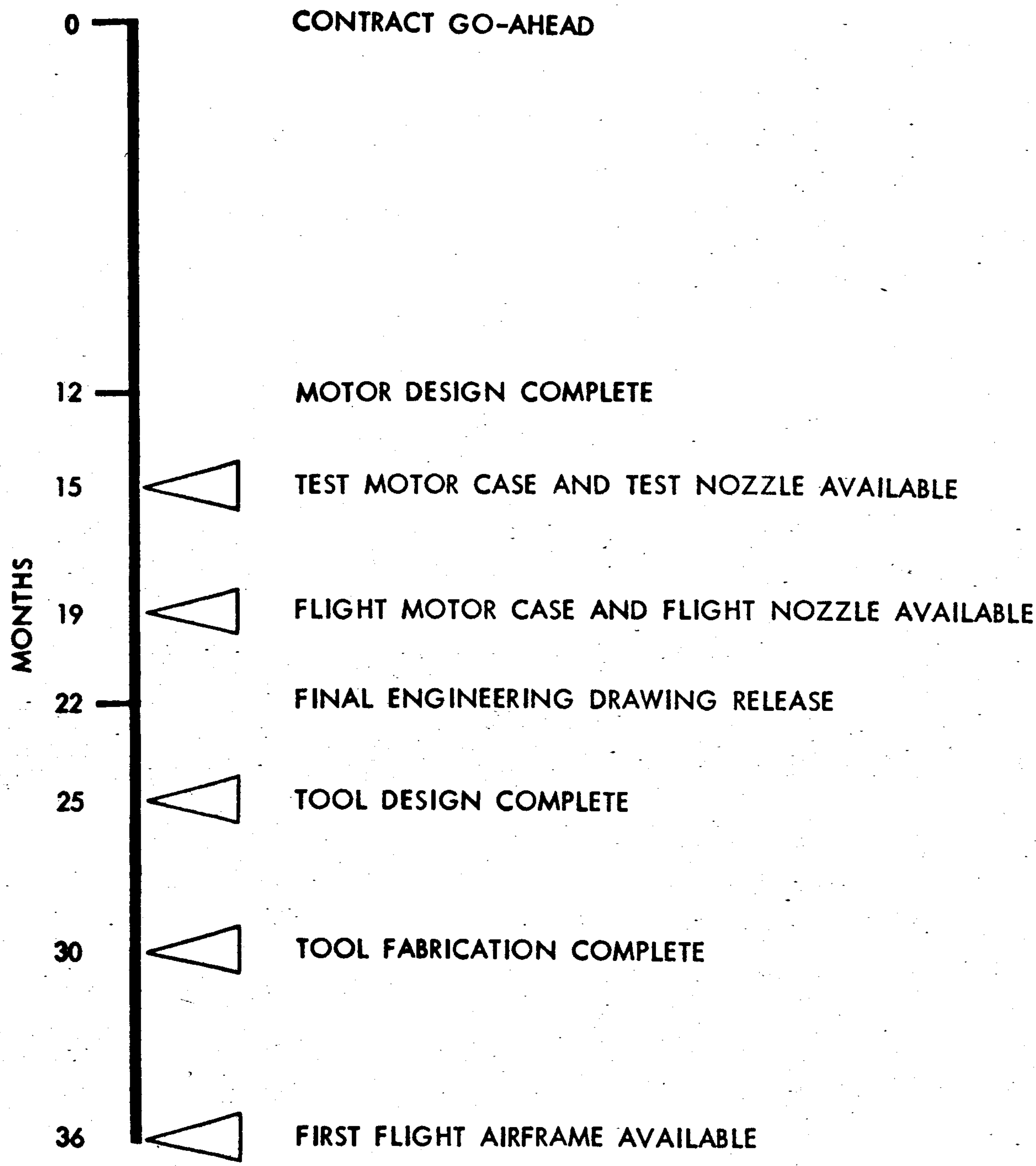


Fig. V-3 MANUFACTURING SCHEDULE HARDWARE AVAILABILITY VEHICLE 1-S1

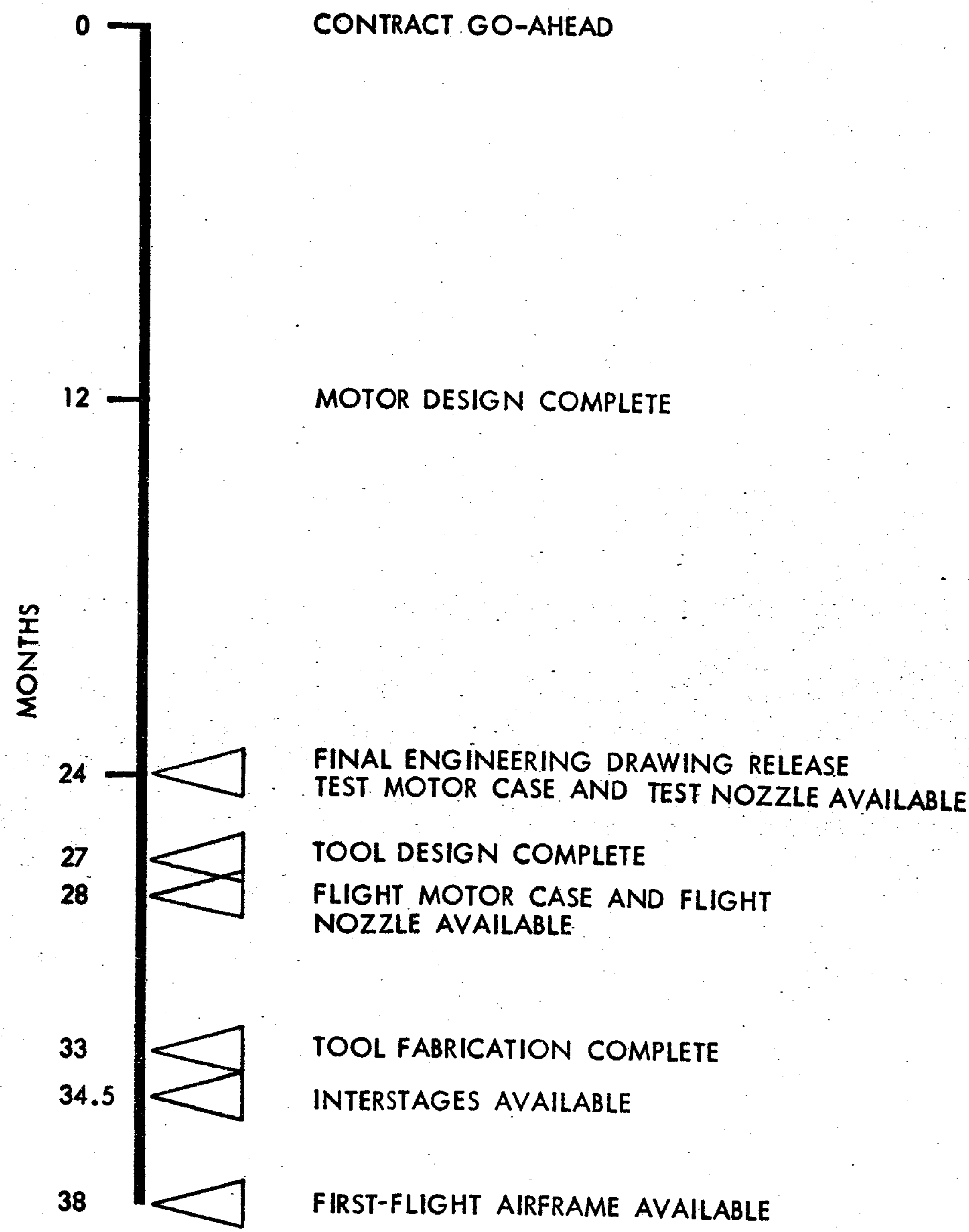


Fig. V-4 MANUFACTURING SCHEDULE HARDWARE AVAILABILITY
VEHICLE N-UC4

1) Receiving inspection and test;
2) Case preparation and propellant manufacturing, casting, and curing;
3) Component subassembly;
4) Systems integration testing;
5) Vehicle assembly;
6) Functional checkout.

RECEIVING INSPECTION AND TEST

Each of the vehicle component fabricators will ship his hardware to the assembly complex. This hardware may be a single valve or a complete nozzle assembly. It is recommended that all possible assembly and testing be done at the subcontractors' plants to minimize the work at the assembly site.

Upon arrival of each component or subassembly at the assembly complex, its records will be checked to ensure compliance with established standards. All components and subsystems will then be inspected to determine that no degradation of performance has occurred during shipment. These inspections will vary from the usual inspections for shipping damage to subsystem tests depending upon requirements for the system involved.

MOTOR CASE PREPARATION AND PROPELLANT CASTING

The motor case components are received from an off-site case manufacturer at the case processing facility (Figure V-5) to be prepared for propellant casting. A detailed plan for segmented case inspection, preparation, and for propellant casting has been outlined under Component Manufacturing. For a large unitized case, the cleaning, insulating and lining operations are similar. The propellant casting, however, will be done by the bayonet method. The case will be positioned vertically on a barge, aft end up. A pipe or hose is lowered through the open end and the propellant is pumped into the case.

An environmental shelter is placed around the case to control the temperature

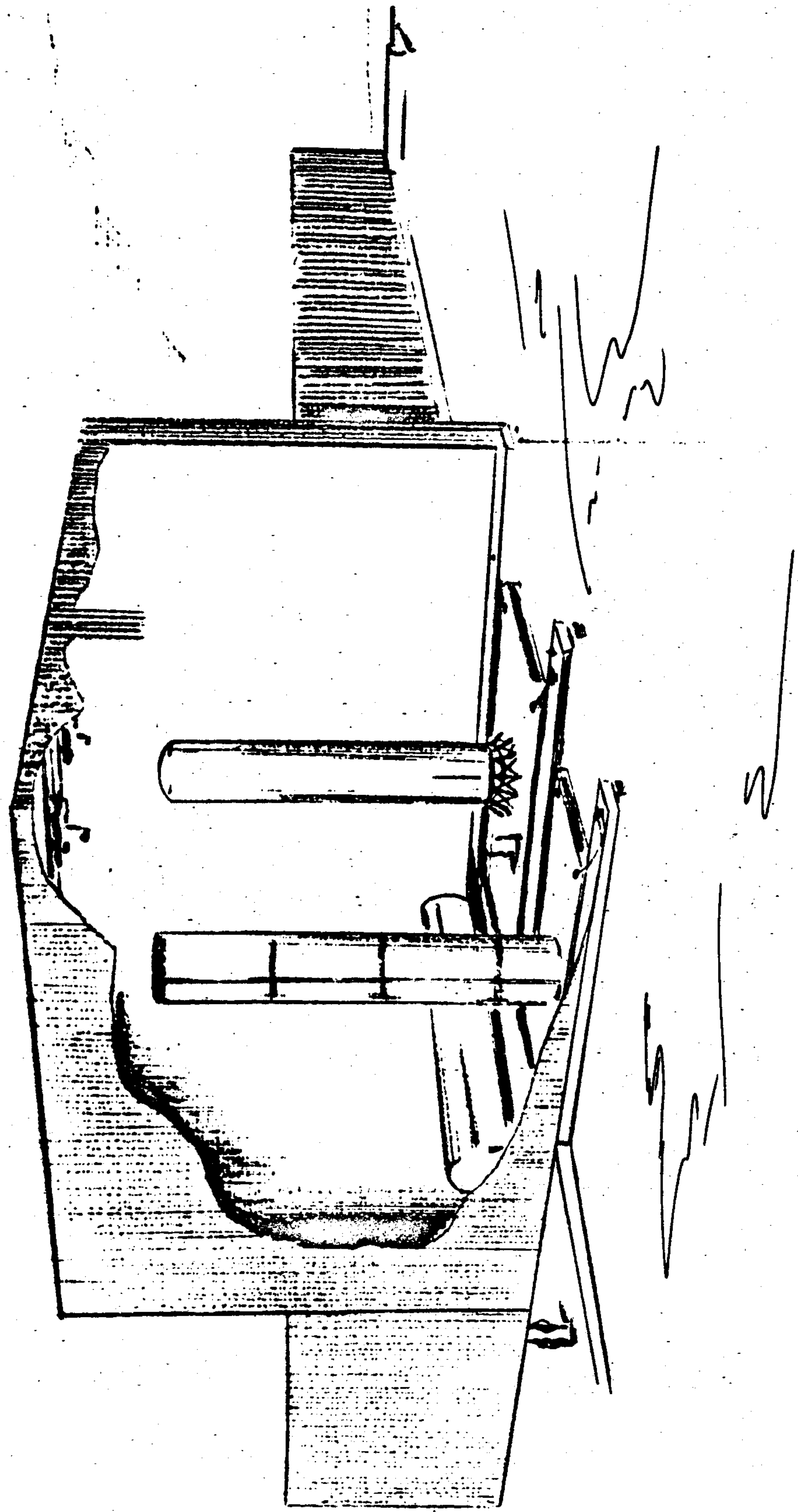


Fig. V-5

during the casting and curing procedures. The propellant manufacturing plant (a new facility) will use the continuous mix process. The propellant will be delivered to the casting site (Figure V-6) in transfer or casting cans of approximately 2-ton capacity. After casting, the motor is taken to the Propellant Curing Facility (Figure V-7) where the propellant is cured and allowed to cool. At the Trimming and Inspection Facility (Figure V-8) the environmental shelter is removed, the mandrel is removed and the motor is inverted to position the aft end down. Radiographic inspection is accomplished here. The accepted motor is then taken to the storage area until three motors are completed and accepted. At that time, final assembly of the vehicle starts. The fourth motor is delivered during assembly.

SKIRT AND THRUST VECTOR CONTROL COMPONENT ASSEMBLY

The structure subassemblies that make up the skirt and the various pressure vessels, valving, tubing, etc., of the TVC systems are assembled into a unit.

SYSTEMS INTEGRATION TESTING

The assembled skirt and TVC unit along with solid motors, liquid second stage, the payload, the second-stage-to-payload interstage and all the other miscellaneous electrical and mechanical components which make up the operating vehicle are taken to the integration laboratory where they are interconnected using flight wiring.

Electrical power will be applied to each system in turn and each system will be checked during power application. A comprehensive operational test of each system will then be conducted to measure its characteristics while connected to the booster wiring. Typical measurements during these tests will include input and output voltage, current, pulse width, frequency, modulation, phase difference, time delays, pressure, temperature, operating times of relays and motors, operating sequences and any other characteristics which apply to specific systems.

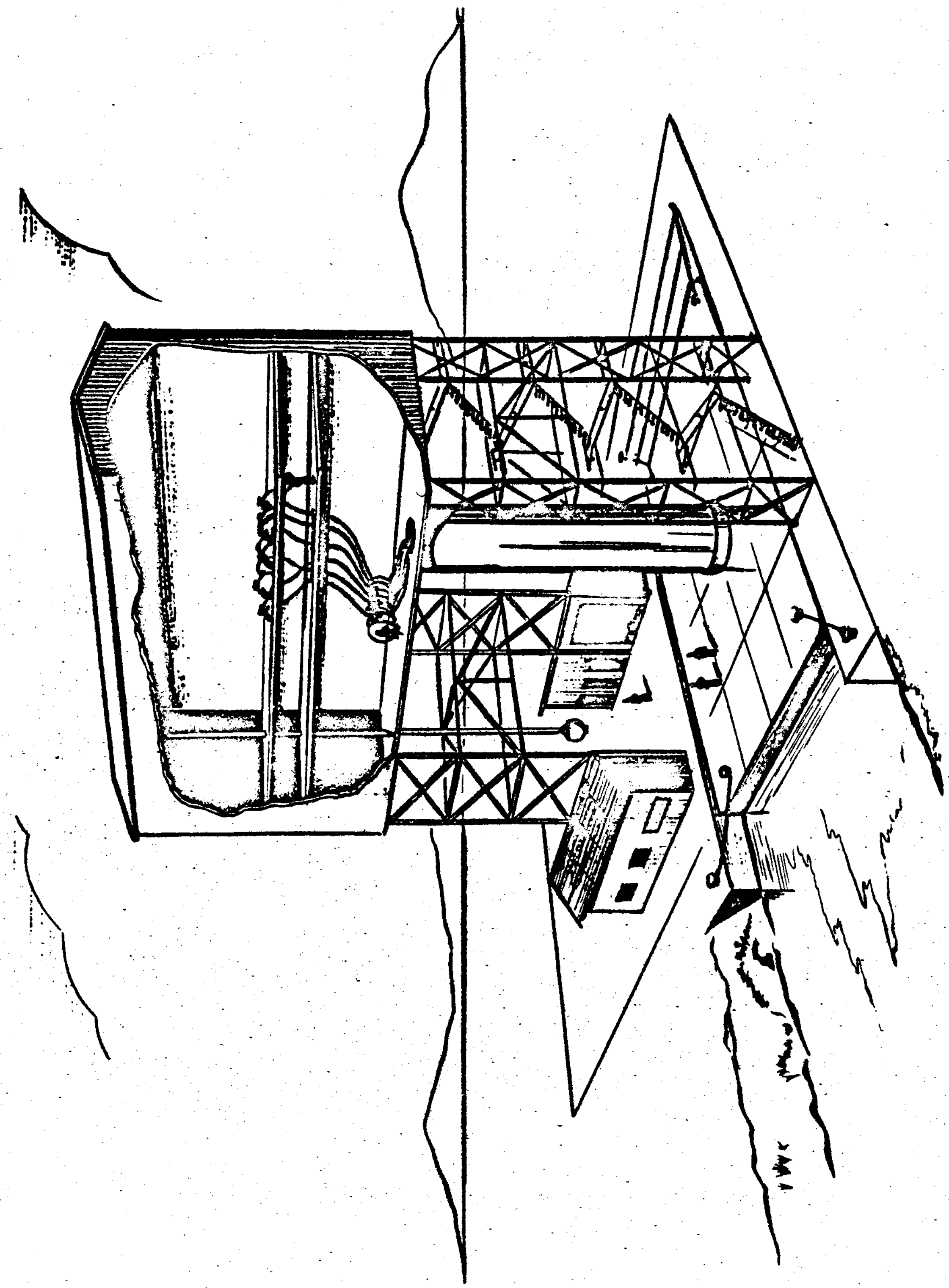


Fig. V-6

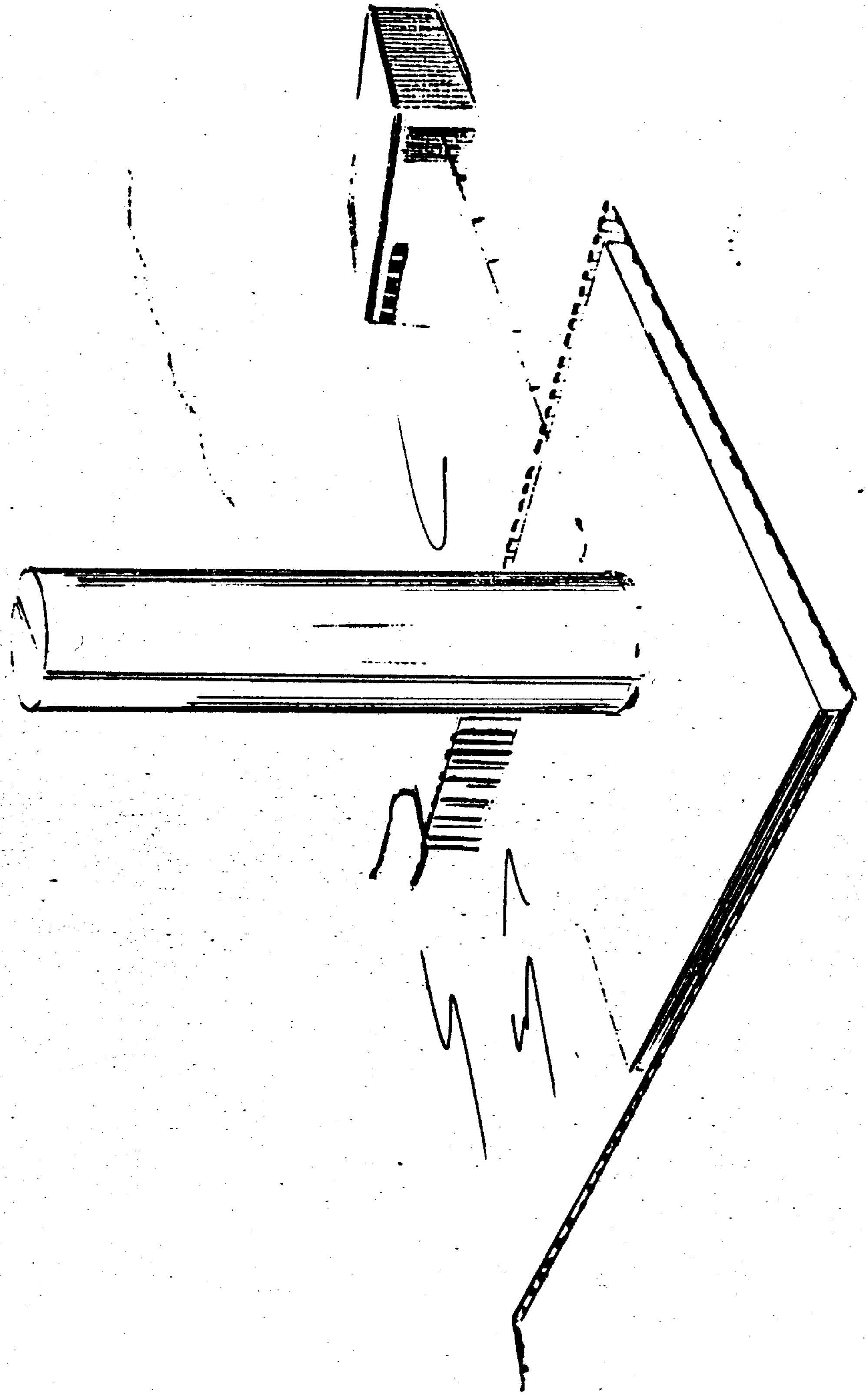


Fig. V-7

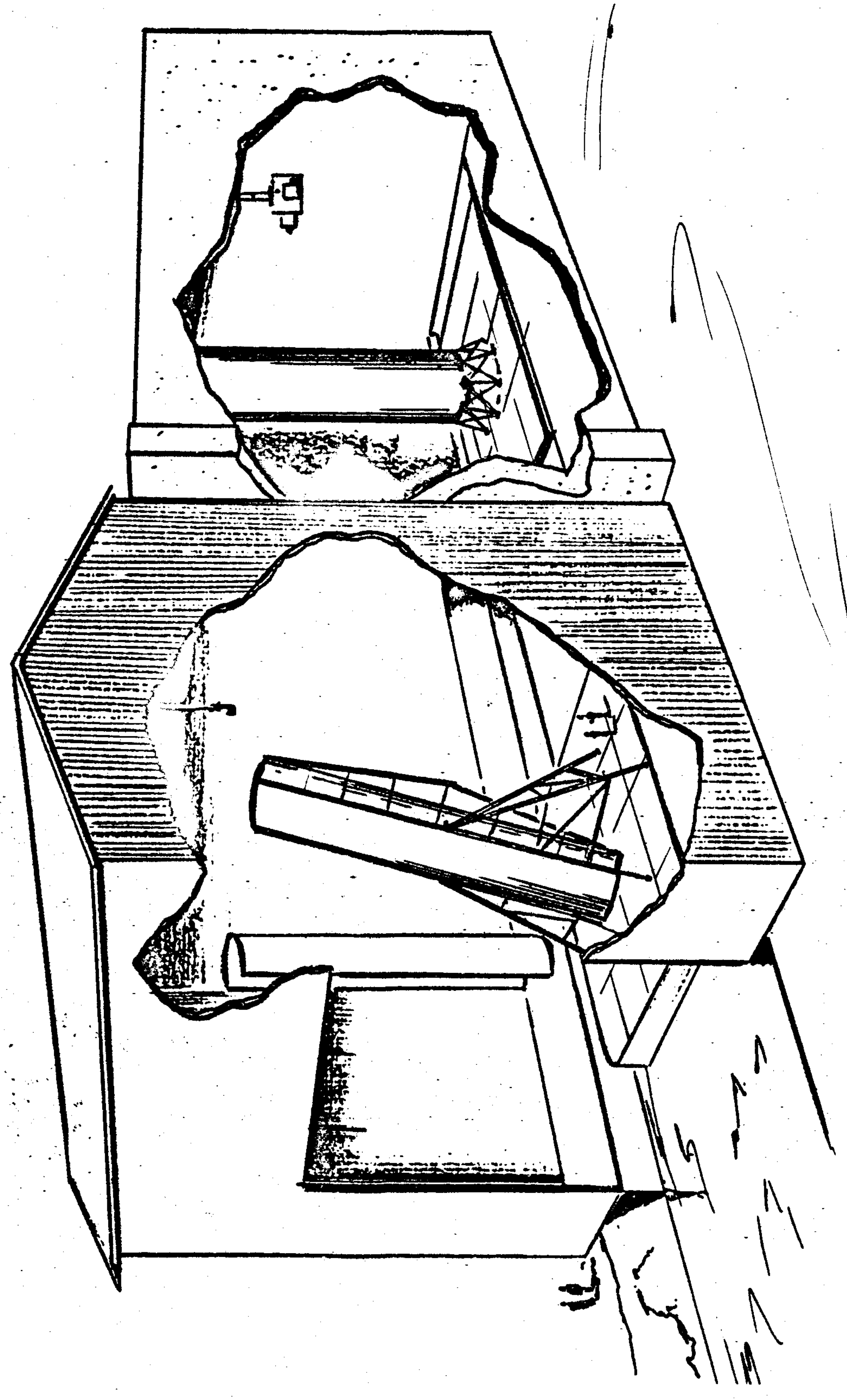


Fig. V-8

After proper operation of each system has been attained, simulated countdown and flight will be performed with all equipment operating in the flight sequence. Other tests will simulate abnormal sequences such as escape and destruct or discontinued countdown.

Completion of integration testing will ensure proper electrical interconnection of systems, and insofar as possible, compatability of electrical interactions among the flight systems and checkout equipment.

Integration testing can be reduced after experience with one booster configuration is gained. However, any configuration changes, including payload changes will require resumption of comprehensive integration testing. It is therefore considered that integration testing will be required throughout the test and operational program.

VEHICLE FIRST-STAGE ASSEMBLY

The vehicle support assembly, the nozzles, the skirt, and TVC assembly (after integrational checkout), and the solid-propellant motors are brought together for assembly into the vehicle first stage. The vehicle is assembled on a steel, box-like pallet. A floating fixed-head gantry crane is used to lift the various components onto the assembly pallet (Figure V-9). .

VEHICLE FINAL ASSEMBLY

After the first stage has been assembled, the second-stage liquid engine, complete with nozzles and mated to the interstage structure, is positioned by a stationary land-based crane (Figure V-10). The payload and its interstage structure is affixed in this assembly position along with the various subsystems and interconnecting circuitry.

ASSEMBLY-AREA TESTING

Following assembly of the vehicle, a series of tests will be performed to determine that it is ready to be transported to the launch area. Many of these tests

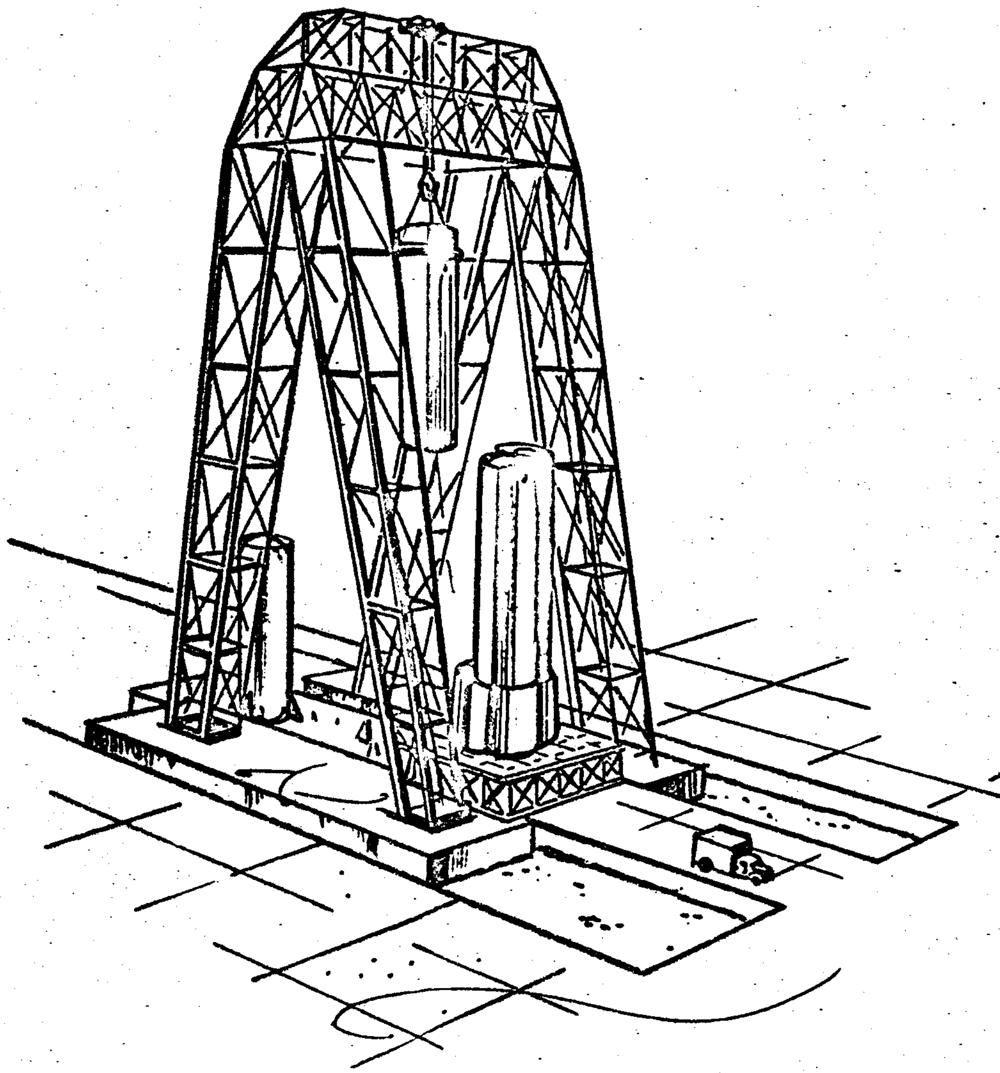


Fig. V-9

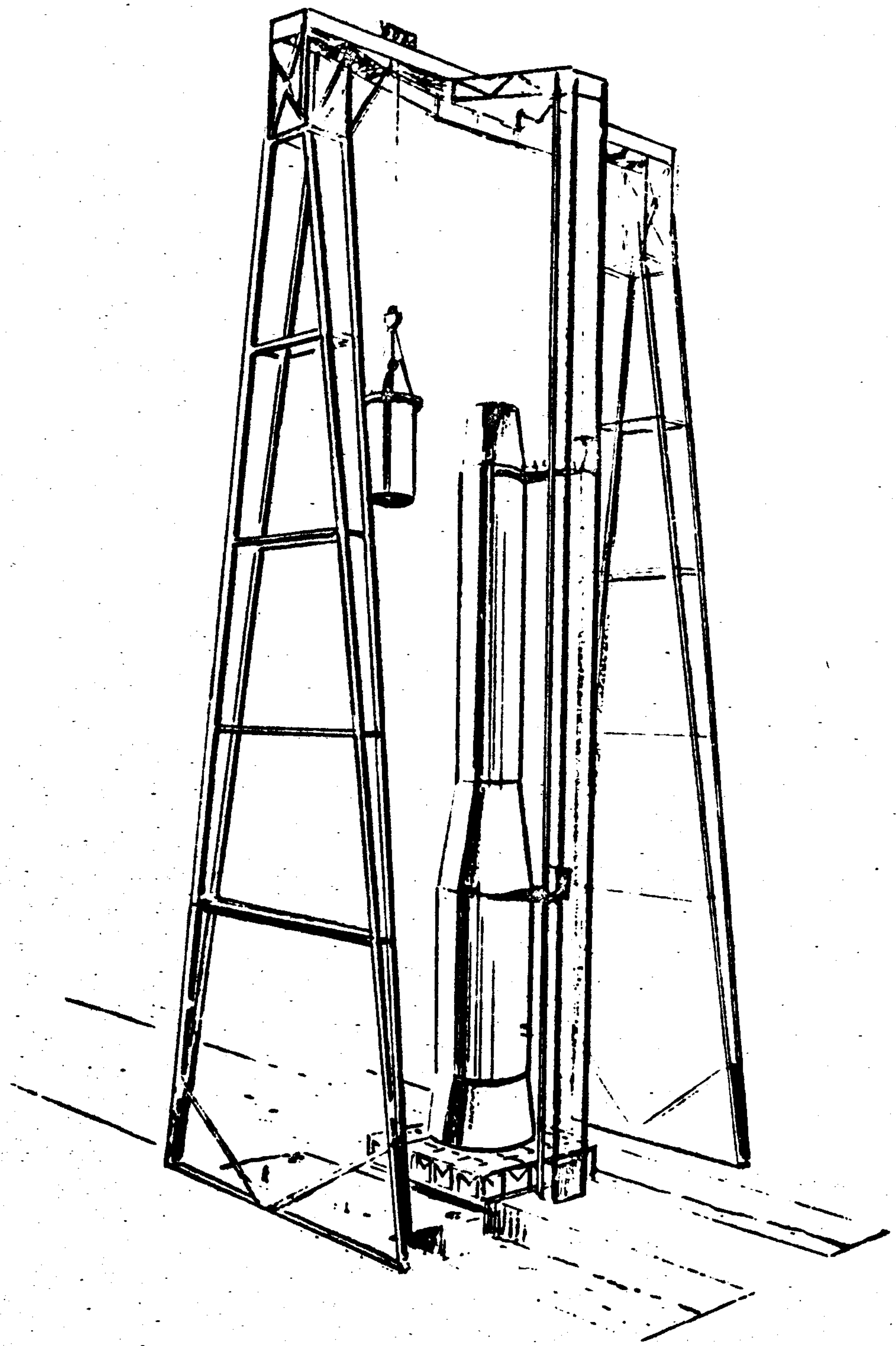


Fig. V-10

will be similar in nature to those performed in the integration area, involving functional tests of individual systems and finally a simulated flight with all systems (including telemetry) operating. Additional functions to be performed in the assembly area will include tests of abort-system sensing and telemetry-channel verification and calibration. After successful completion of these tests, flight batteries will be installed, test wiring removed, insulation installed, access panels secured, and the vehicle will be moved to the launch site. A complete list of the tests to be conducted is tabulated on Table V-3.

TEST SCHEDULES

A system-integration schedule (Figure V-11) and an assembly schedule (Figure V-12) for the NOVA-class vehicle (N-UC4) indicate the time required for each of the tests relative to hardware-availability dates.

After the postassembly and functional checkouts have been completed, the assembled vehicle, still on its pallet, is moved to the launch area (Figure V-13).

C. LAUNCH OPERATIONS

1. GENERAL CONCEPT

The launch-operation concept assumes that nine vehicles have been fired in tests to prove the vehicles have met design requirements in the areas of design mission, reduced dynamic pressure, maximum heating and load tests, maximum wind shear, escape at maximum dynamic pressure, and escape at maximum first-stage acceleration.

Most of the major technical difficulties and operational problems inherent in a new system are presumed to have been resolved during this research and development phase.

Table V-3

LISTS OF TESTS BEFORE FLIGHT

Receiving Area

Functional test of each system received

Integration Area

a. Initial connection and power application

b. Ordnance-systems test

c. Destruct-system operation

d. Safe-and-arm devices test

e. Tracking systems

f. Guidance and control system

g. Telemetry systems

h. Payload operation

i. Escape-system sequencing

j. Staging-sequence tests

k. Liquid-engine sequencing

l. All-systems simulated flights

Assembly Checkout Area

a. Power applications

b. Ordnance

c. Destruct

d. Safe and arm

e. Tracking system

f. Guidance and control system

g. Telemetry commutation, modulation, channel verification

h. Payload operation (all payload systems that are operated in flight with booster)

i. Escape system

j. Staging sequence

k. Second stage

l. Hazardous current

m. All-systems simulated flight

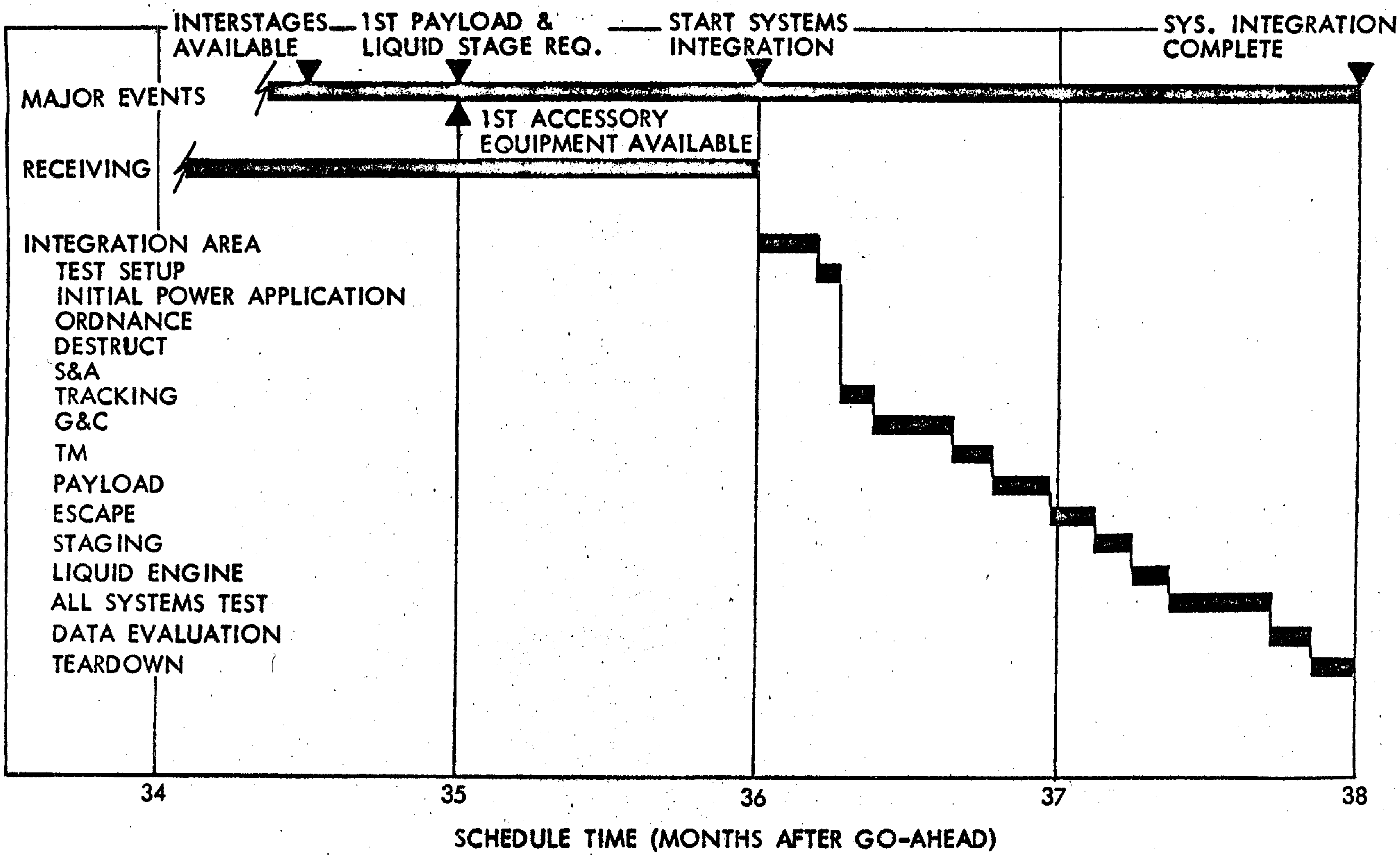


Fig. V-11 SYSTEM INTEGRATION SCHEDULE
(CONFIGURATION N-UC4)

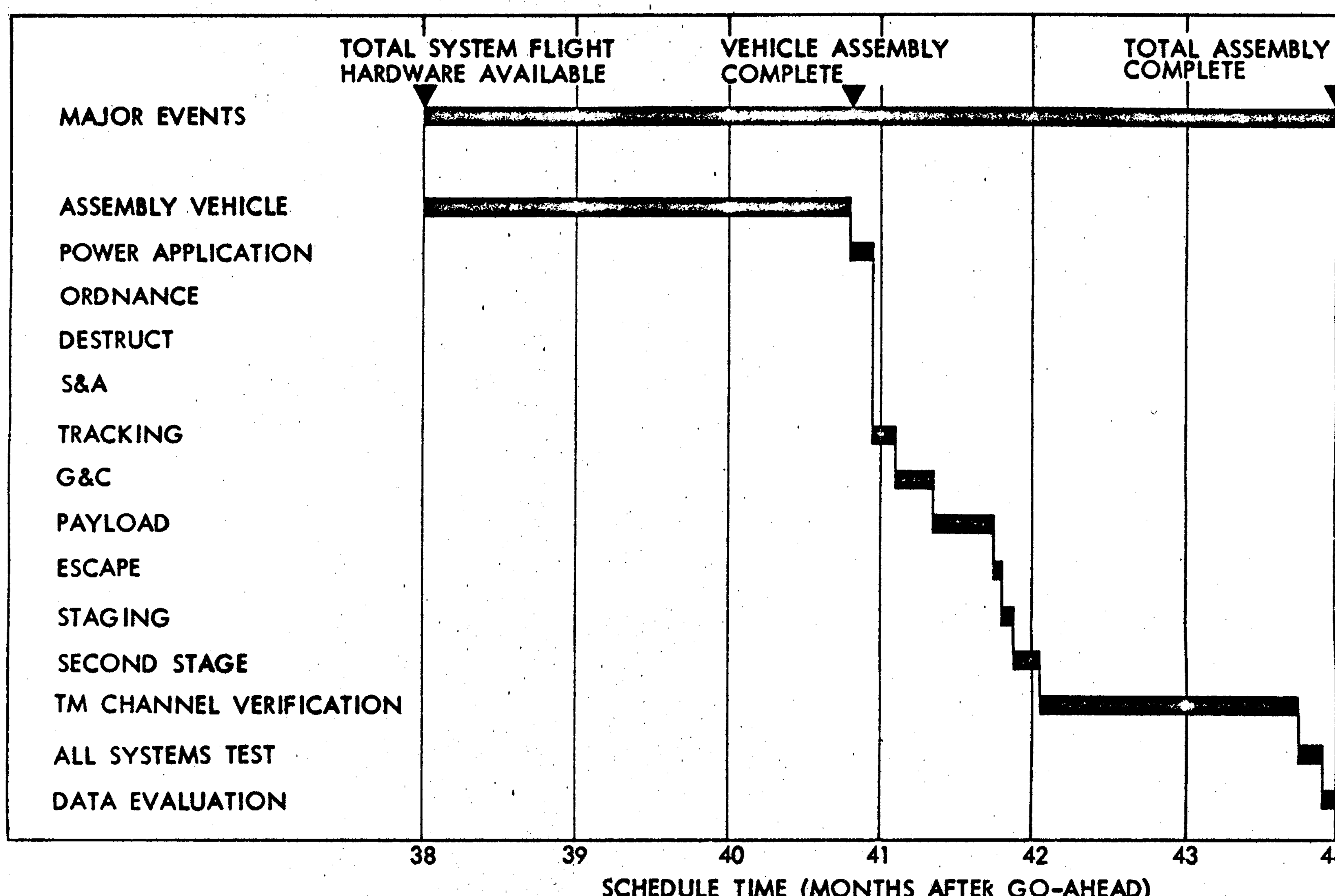


Fig. V-12 ASSEMBLY SCHEDULE
(CONFIGURATION N-UC4)

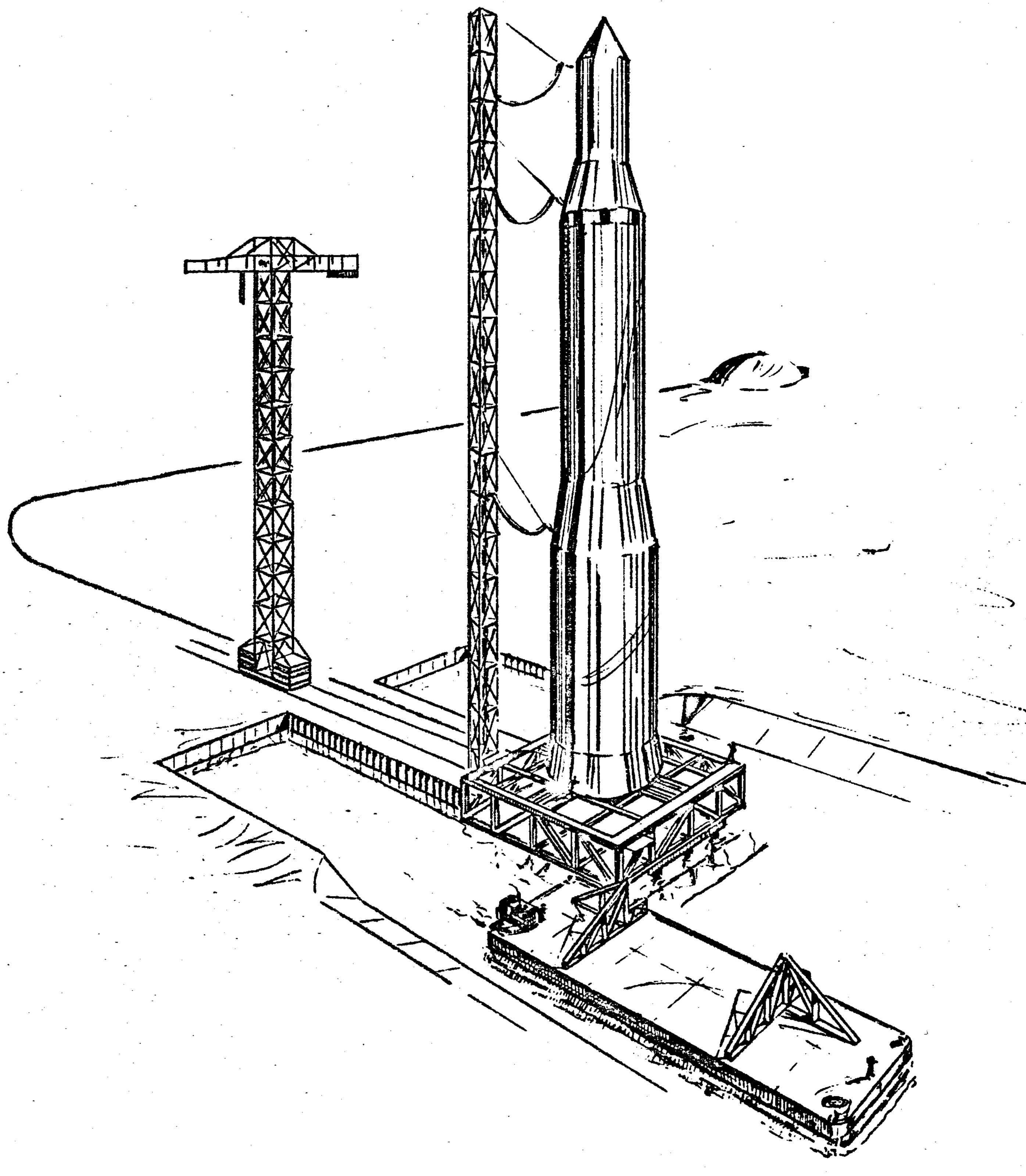


Fig. V-13

2. LAUNCH CONCEPT

Several manned payloads are planned. In view of the large investment in vehicles and equipment, a checkout of the complete vehicle on the launch pad is required. This checkout would be similar, although simpler, than that performed during final assembly. This final launch-area testing should decrease as test and flight experiences is gained as the program progresses, and increased confidence in the system is established.

Maintainability principles will be applied to system design so that defective items encountered during checkout may be removed and replaced, with minimum penalties to the test program or launch schedules. These principles will include: adequate quantity, location, and size of access panels; location of items to facilitate removal and installation at the launch pad; electrical and pneumatic-hydraulic test connections located for easy accessibility and such that, upon subsequent disconnect, no degradation in vehicle performance will result; and the use of standard and proven items whenever feasible. For the vehicle, the concept of of repair by replacement of modules will be followed for launch-pad operations. Replaced components will be returned to the manufacturing facility or applicable vendor for rework. Scheduled maintenance and calibration checks will be accomplished on ground support equipment items. Unscheduled GSE maintenance requirements will be performed as required, with repair accomplished on-site if possible, and with component repair again accomplished at the manufacturing facility or applicable vendor.

3. LAUNCH SEQUENCE

VEHICLE CHECKOUT

The vehicle is prepared for movement to the launcher station following final assembly and test. The barge is lowered in the water by injecting water as ballast until the top deck will clear the assembly and launcher pallet. The barge is then moved into position under the pallet and secured in position while water is pumped out of the ballast tanks, raising the launch pallet with its vehicle until it clears its support structure. The complete vehicle and pallet is moved on the barge to the launcher station and secured in position. The vehicle and launch pallet are lowered into position again by filling the ballast tanks, thereby lowering the barge until the pallet rests on the launcher pallet supports structure. The barge is then moved to clear the launch pad and returned to the manufacturing area.

The major items in the launch-complex breakdown are shown in Figure V-14 while the vehicle breakdown is shown in Figure V-15. After the launcher pallet is secured, the launch-pad service tower is moved into place alongside the vehicle launch pad.

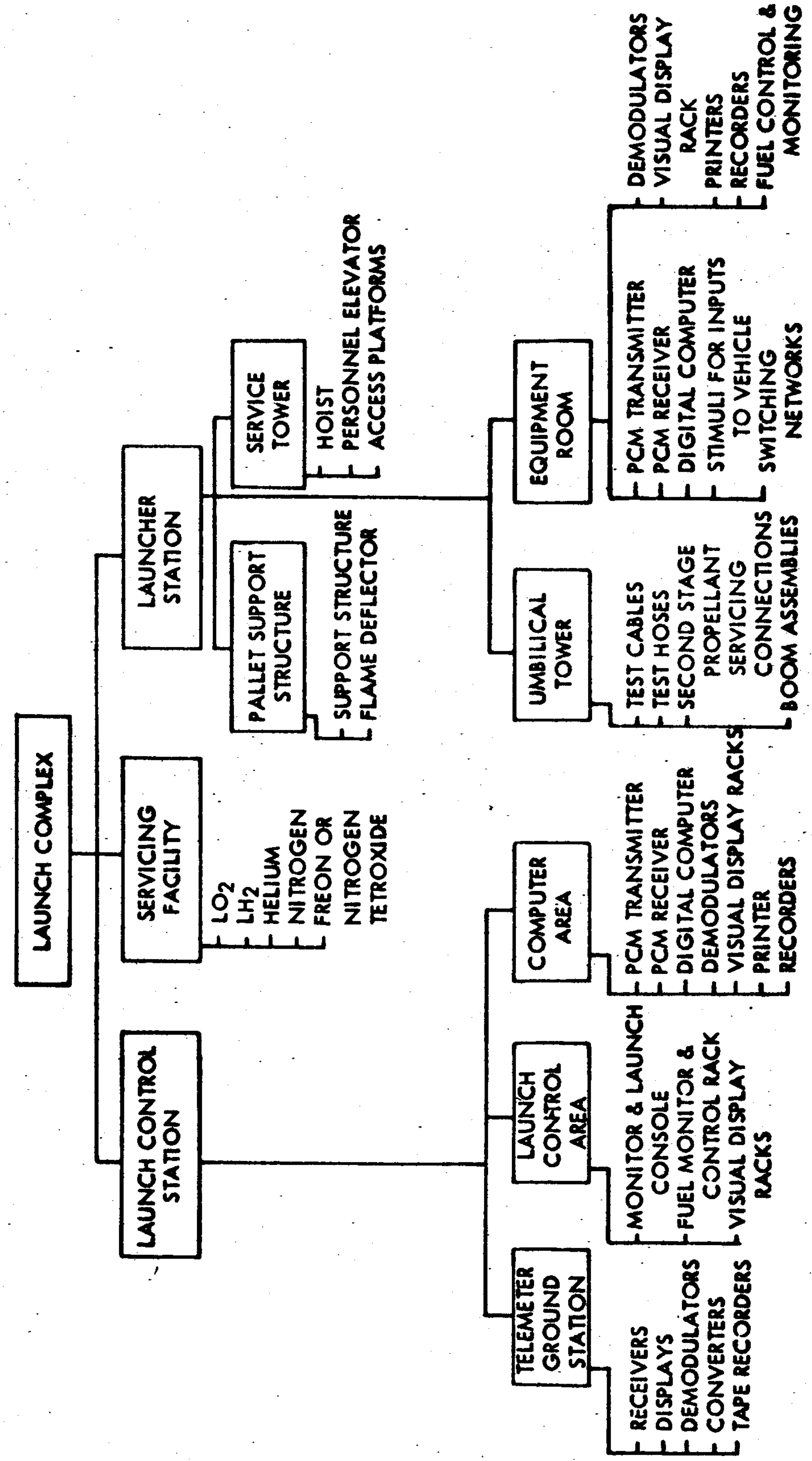


Fig. V-14 LAUNCH COMPLEX BREAKDOWN

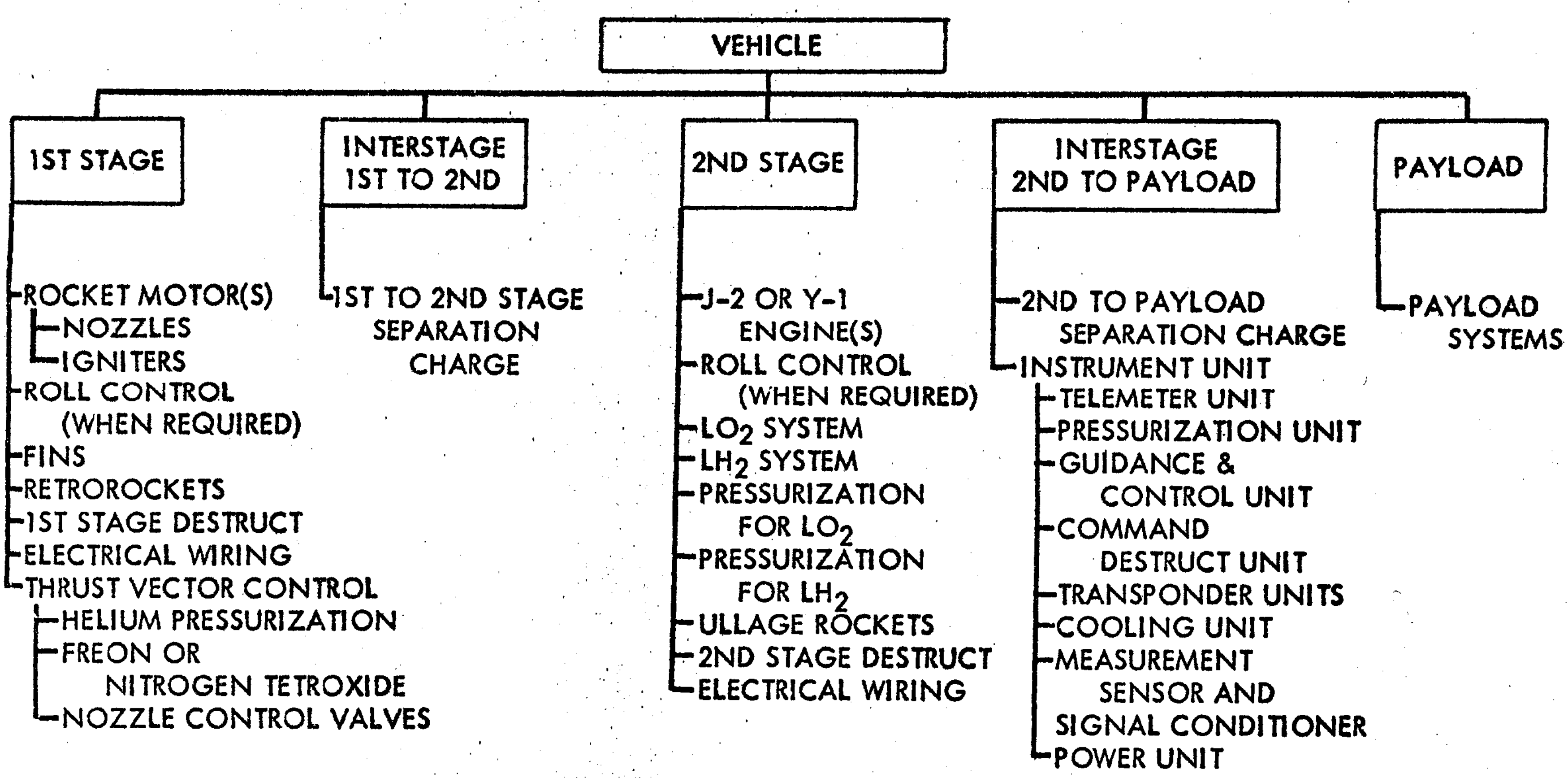


Fig. V-15 VEHICLE BREAKDOWN

From the fixed umbilical tower, the umbilical electrical and pneumatic-hydraulic connections are made to the first stage, second stage and payload, and the vehicle is prepared for checkout.

Some of the vehicle tests are not possible using automatic programed tests and evaluations. Therefore, manual and/or semiautomatic tests will be performed first. Typical tests will include leak tests of the first-stage rocket nozzle(s), thrust-vector control, and associated helium pressurization system. In the second stage, typical tests are torque tests of the J-2 or Y-1 LH_2/LO_2 engines, leak tests of the engines, and gaseous hydrogen and gaseous oxygen pressurization systems.

After completion of the manual and semiautomatic test, the computers at the launcher station and the launch-control station will receive a self-check, which will determine that the checkout equipment is within tolerance and all displays are working properly. The first stage would then be checked using the program stored in the two computers. This will include operational tests of the thrust-vector-control system and associated helium pressurization system, operational and calibration checks of the telemetering system, operational tests of the command destruct system, and tests of the stage separation and destruct system wiring and electrical wiring. The roll control for vehicle 1-S1 would receive an operational check.

A checkout on the second stage would then be performed. This would include an operational check on the following systems: liquid hydrogen and oxygen; gaseous oxygen and hydrogen pressurization; nozzle(s) gimbaling, which includes the hydraulic system; guidance; Azusa; C-band transponder; electrical power and associated wiring; liquid oxygen and hydrogen valve heating; and command destruct. The telemetering system would receive a calibration and operational check. The stage-separation (ullage and retrorocket) and destruct systems wiring would be checked and the engine-starting sequence and shutoff sequence would be checked for proper operation.

The details of the payload subsystems were beyond the scope of this study. Therefore, the checkout of this part of the vehicle was considered as one function. It would be similar to the second-stage checkout, and the time allowed is based on the normal systems expected in a manned payload, and could decrease considerably should the payload be structured for a space station or a similar type of payload. The manned-payload system would probably include the following systems: escape; environmental; guidance and control; life support; telemetering; data link (voice and information); propulsion; electrical; hydraulic; displays; and transponders. Upon completion of the vehicle checkout, all cables and hoses used only during testing will be removed from the fixed umbilical mast to prevent damage to them during launch.

A simulated launch would be performed. This would include a check with the range facilities on the proper operation of all vehicle telemetering transmitters and transponders without radio-frequency interference; in addition, the ability of the guidance computer to switch from the first to second stage would be checked. The generation of timed signals, such as second-stage engine-starting sequence and shutoff, will be checked. A compatability test between first stage, second stage, and payload will be performed. The retraction of all umbilical connections and umbilical arms will be checked for proper operation.

On the day before launch and after completion of a simulated launch, the thrust-vector-control system would be loaded with Freon or nitrogen tetroxide, and the associated helium pressurization system would be partly filled to 1500 psi. The gaseous-nitrogen systems would be partly filled to 1500 psi.

OPERATING PROCEDURES

Competent design, with meticulous attention to detail, and the use of detailed procedures outlining step-by-step the tasks to be performed will ensure that the launch is performed without errors. These written procedures and check-off lists, together with thorough training of launch crews will ensure satisfactory accomplishment of necessary functions in proper sequence.

LAUNCH-CONTROL AND DATA-SYSTEMS CHECKOUT

The launch-control system includes the launch monitor control, the computer, displays and recorders at the launch-control station, and the computer, display and fuel control, and monitoring equipment at the launcher station. This equipment serves the two functions of launch monitor control and final checkout of the vehicle at the launcher station. For all except the bimonthly launch rate, schedule maintenance will be performed on second and third shifts. Scheduled maintenance will consist of calibration and checkout of the launch monitor control, computers, recorders, displays and fuel-measuring equipment, and replacement of limited-life items. Unschedule maintenance will be performed as required and it is expected that a good portion of this can be accomplished by repair of defective items.

LAUNCH-PAD REFURBISHMENT

During normal vehicle launching, it is expected that part of the thermal insulation coating on the booster assembly pallet will be damaged. The pallet will be scheduled through the repair facility to replace the thermal insulation coating. The pallet structure should be undamaged. It may be necessary to replace the main structural members and/or the support base ring after several firings. The flame deflector can be replaced, however, it will be a time-consuming task. No damage to flame deflector is expected as it is in the water and will be cooled. The umbilical tower and cables are expected to be undamaged during a normal launch. The umbilical support arms can be readily replaced. Individual umbilical cables running up the tower can be replaced when required. The propellant transfer lines supported by the tower can be replaced if they are damaged.

4. LAUNCH SCHEDULING

FINAL CHECKOUT

Schedules for the six vehicles are shown in Appendix 2, Figures AV-11 through -14.

These schedules are based on the first operational launch following the launching of nine vehicles scheduled for the R & D program and that the digital test equipment has been used and proven satisfactory.

As operational experience is gained and system confidence is established, operating times are expected to decrease. By the twelfth operational launch, it is anticipated that the 1-S1 vehicle will require five working days, the 3-SC4 and the 3-UC4-vehicles six days, the 4-UC4 and 4-UC6L-vehicles eight days, and the N-UC4-vehicle nine days at the launcher station. These decreased times are based on increased confidence in final assembly testing, on improvements in techniques and methods, and the corresponding decrease in launcher-station testing as data gathered during vehicle checkout, firing, and flight are evaluated.

COUNTDOWN

Launch countdown procedures will vary with different types of payloads. Accordingly, a separate countdown sequence will be developed for the first stage and second stage instrument unit and these will then be integrated with the selected payload countdown to achieve an overall vehicle countdown sequence. Based upon the information available, a preliminary countdown sequence has been developed and is shown in Appendix 2, Figures AV-17 and -18.

5. RANGE SAFETY

Special safety considerations are required in the areas of solid-propellant handling, high-pressure piping and vessels, nitrogen tetroxide (for the N-UC4-vehicle) and range safety.

The hazard classifications assigned to propellants are classes 2, 9, and 11. Class 2 propellants are those oxidizers and inflamable materials that primarily present a fire hazard. Class 9 propellants are those hazardous mono-propellants with oxygen values high enough to provide an oxygen-combustible balance capable of producing complete or essentially complete combustion. Such a mixture can rapidly develop large amounts of heat and, in consequence, borders on or is comparable in potential danger to high explosives. Class 11 propellants are those hazardous oxidizers and combustible materials that present primarily a potential poisoning hazard and require storage in sealed containers. If leaks, high temperatures, fires, or the corrosion of containers permits contents to escape, this class of propellants (alone or by reaction with air) produces persistent, highly toxic clouds. These clouds may travel considerable distances under favorable atmospheric conditions before dissipating to concentrations no longer harmful.

Two distinct areas, hazardous and nonhazardous, are involved in solid-propellant vehicles. The hazardous classifications of the various vehicle sections are shown in Table V-4.

For the N-UC4-vehicle using nitrogen tetroxide for thrust-vector control, additional procedures will have to be developed for storing nitrogen tetroxide, for filling the N_2O_4 tank, and for personnel working around the vehicle after this propellant is loaded. Vapor concentrations greater than 1/2 part per million in air are considered hazardous to personnel, and a means to monitor the concentration will be required. For personnel handling nitrogen tetroxide, special training as to the hazards, protective clothing, and protective breathing devices will be required.

For the overall hazardous area, only personnel essential to operations being performed in the area will be allowed. Controls will be developed to monitor personnel in each hazardous section. An evacuation plan for each section and for the entire hazardous area will be developed. Sufficient transportation must be located at each station for immediate use in case such action is required. All personnel must be properly trained in their specific tasks and must follow written procedures and rigid check off lists when performing these tasks.

At the launcher station, three major safety precautions are required for the first stage: installation of the igniter and/or initiator as late as possible during count-

Table V-4

Hazardous Areas

Class 2 (unitized motors only)

1) Storage area for materials used in propellants.

Class 11 (N-UC4-only)

1) Nitrogen tetroxide storage area.
2) Launcher station for N-UC4-vehicle when nitrogen tetroxide tank is filled

Class 9 (unitized motors)

1) Propellant-Mixing Facility
2) Propellant-Pouring Area
3) Motor-Curing Area
4) Motor-Inspection Area
5) Barge—Unitized-motor transporter (when transporting motors)

Class 9 (all vehicles)

1) Final Assembly Area
2) Launcher Station (when vehicle installed)
3) Barge—Assembled Vehicle Transporter (when transporting vehicle)

down: preventing the solid propellant from being ignited by a fire in launcher station areas; and assurance that pressure vessels are not charged to their operating pressures while personnel are stationed near the vehicle. Rocket nozzle plugs installed in the nozzles while the vehicle is being prepared for launch will prevent small fires from igniting the rocket propellant. On the 1-S1 vehicle a protective cap should be placed over the igniter until the initiator is installed. Connection of wiring to the igniters and/or initiators, destruct packages, stage-separating charges, and ullage and retrorockets should be delayed until as late as possible in the countdown sequence.

During vehicle launch, the acoustical noise generated is an additional hazard. The major safety considerations are the physical location of the launcher station in respect to the other facilities, protection of personnel by limiting their exposure to noise, and control over the location of personnel during vehicle launch. The launch-control station will be designed to protect launch personnel from acoustical noise.

Range-safety equipment must be installed at the launch complex or an adjacent area. Typical of these items are surveillance and tracking equipment, both ground installed and airborne radars; computing equipment, including tracking, plotting, and impact prediction; optical tracking equipment, which will include a vertical wire screen to determine that the vehicle is on the programed flight trajectory; television cameras to allow the launch-control station to monitor the vehicle at launcher station; and dual-command destruct transmitters to destroy the vehicle if required. The vehicles will require radar transponder, Azusa transponder, two command-destruct receivers, and telemetering equipment. These items are the same as presently required for vehicles using liquid first stages.

6. LOGISTICS

GENERAL

This study does not include the standard fuels and servicing requirements of liquid boosters. Liquid oxygen, liquid hydrogen, Freon, hydrogen peroxide, nitrogen tetroxide, helium, and nitrogen will be required in large quantities to support the launch schedules. These items will probably be Government furnished and, except for Freon, nitrogen tetroxide, and hydrogen peroxide, will have been furnished in large quantities for other programs.

Spares, publications, transportation from manufacture to assembly area, and servicing requirements of the payload are not included because they are beyond the scope of the study.

MANPOWER REQUIREMENTS

The three required tasks in the launch complex are vehicle checkout, vehicle launch operations, and maintenance of the equipment in the launch-control area and launcher station. It is assumed that most of the personnel used during vehicle launch are trained in vehicle checkout and can be used during these operations. The total manpower required for the above tasks are 150 men for the 1-S1 vehicle and 171 men for the N-UC4 vehicle. From the available information, no significant difference in manpower can be determined for vehicle launch operations and maintenance requirements. The manpower required for vehicle checkout does vary with vehicle size and the N-UC4 requires 40 percent more personnel than the smaller 1-S1 for this function alone.

Manpower requirements do not include personnel for range tracking radars, visual tracking devices, or data processing, as the requirements for these vary considerably with mission requirements.

Table V-5 gives a functional breakdown of the three major tasks and the manpower required for each functional area.

Table V-5

MANNING REQUIREMENTS

1) Launch Operating

Functional Area	Launch-Control Center	Launcher Station
Payload	14	6
Second Stage	12	6
First Stage	6	2
Data System and Launch Control	6	12
Total	38	26

2) Additional Personnel Required for Maintenance—Launch Control Area and Launcher Station

Function	Launch-Control Center	Launcher Station
Data System and Launch Control	13	15
Fueling and Servicing	-	6
Total	13	21

3) Additonal Personnel Required for Vehicle Checkout

Functional Area	1-S1 Configuration	N-UC4 Configuration
Payload	8	13
Second Stage	8	13
First Stage	6	11
Data System and Launch Control	6	6
General Duty	24	30
Total	52	73

4) Total Personnel Required

Function	1-S1 Configuration	N-UC4 Configuration
Launch Operations	64	64
Maintenance	34	34
Vehicle Checkout	52	73
Total	150	171

SUPPLY REQUIREMENTS

These vehicles will require spares support after delivery, and during system integration, final assembly, and checkout at the launcher station. It is anticipated that the payload contractor will furnish the spares required to support the payload. The second stage will require spares support at the launch site after delivery from the manufacturer. The average spares costs for this stage per vehicle are expected to be: electronic equipment, 12 percent of the electronic system costs; mechanical, 8 percent of the mechanical system costs; propulsion, 10 percent of the propulsion system costs; and structures, 2 percent of the costs. Average first-stage spares costs per vehicle are estimated as: electronic, 12 percent of the electronic system costs; mechanical, 8 percent of the mechanical system costs; propulsion, 1.5 percent of the propulsion system costs; and structures, 2 percent of the structure costs.

Ground support equipment will be used continually throughout the 10-year program and spares are expected to average 16 percent per year for electronic-type checkout equipment and 12.5 percent per year for mechanical-type checkout equipment.

The barge pumping system used to raise and lower the launch pad and vehicle will require spare parts estimated to cost 6 percent per year of the installed-pumping-system costs.

Fueling and servicing facilities will require spares support estimated to amount to 8 percent per year of the initial facilities costs.

MAINTENANCE REQUIREMENTS

Unscheduled vehicle maintenance during checkout and launch countdown will consist of replacing defective items uncovered during launch-pad testing of the vehicle. The launch-control-area equipment and launcher-station equipment will require scheduled maintenance that will include calibration, functional testing, and replacement of limited-life items. Unscheduled maintenance will be performed only as required. During launch countdown, items will be removed and replaced by serviceable items whenever possible to decrease the delay. Detailed schedules will be developed during the research and development phase. The scheduled intervals will probably start after every launch and, as the program progresses, the amount of work scheduled between launches should decrease. By proper scheduling the maintenance workload between launches, all inspections can be made with a constant workload for the launch-complex personnel.

For the 10-launches-per-month rate for the smallest vehicles, it would be possible to have a special maintenance crew perform scheduled inspections on the five launch complexes. This would decrease the manhours for scheduled maintenance and improve the caliber of inspections. Offsetting this, however, are the disadvantages of coordination between maintenance crews and launch personnel, decrease in launch-crew confidence in equipment, and increases in delays during vehicle checkout and launch because of decreased skills and knowledge of the launch crew. No clear conclusions can be drawn at this time. Initially the program should be implemented with launch-complex crews being responsible for scheduled maintenance. A firm decision can then be made regarding the adviseability of special maintenance crews as experience dictates. The lower launch rate of the larger vehicles, operating from fewer launch pads, justifies using launch crews for both maintenance and launch functions.

A firm configuration control for the launch complexes must be started early in the program. If technically possible, all launch complexes should be the same for each type of vehicle to eliminate confusion, decrease the number of spare items required, decrease the possibility of errors in procedures, and decrease the number of human errors because of launch-complex differences.

VI. FACILITIES

A. DEFINITIONS

Facilities must be provided for three basic operations: manufacture, assembly and checkout, and launch. The majority of the manufacturing will be done at existing locations scattered throughout the country and the majority of the assembly and checkout and all of the launch operations will be accomplished at a single integrated base.

Manufacturing facilities for large solid-rocket engines consist of two main divisions: those for hardware items (engine case, nozzle, interstages, and accessory items); and those for propellants. The processes and functions involved in these manufacturing operations are basically the same for segmented and unitized configurations, although methods and facilities vary in some instances due to required differences in handling and transportation techniques.

The manufacturing of hardware items can be accomplished with existing facilities. While some deficiencies exist, present plants may be supplemented at less cost than constructing new plants. It is likely that these supplemental facilities will be supplied by private capital. Some restrictions will be experienced in transporting larger items from existing facilities but they are not prohibitive and may be resolved without construction of entire new facilities. The use of existing facilities will eliminate the problem of transferring skilled personnel and establishing new organizations—preventing program delays from these causes.

The study has revealed that existing facilities cannot accomplish all phases of the propellant manufacturing task. Existing facilities, with minor supplements, are adequate to accomplish the development and low-rate production of segmented engines. Existing facilities do not have the capability, nor may they be easily supplemented, to accomplish the large unitized engine development or production. Also, transportation difficulties for the large unit engines preclude consideration of existing facilities. A deficiency will be encountered in the supply of ammonium perchlorate for the high production rates. Since this shortage would exist later in the program, additional facilities could readily be made available by private capital if adequate incentives and guaranteed recovery are established early.

The unique requirements for assembly and checkout facilities necessitate new facilities.

There are now no suitable facilities available from which to launch these vehicles. It is possible that with major revisions Saturn launch complexes No's. 34 and 37 could serve to launch the 1-S1 vehicle; however, it is felt that the cost of revisions would approximate the cost of new facilities. If new facilities were built in the vicinity of Cape Canaveral, existing tracking and downrange facilities could be used.

B. MANUFACTURING FACILITIES

1. HARDWARE MANUFACTURING FACILITIES

ENGINE CASES

Investigation of manufacturing plan requirements shows that solid engine case manufacturing techniques are similar to those for segmented and unitized configurations. The significant difference is that the segments are machined on the ends and the unitized case is made by welding the individual sections together at the case manufacturing plant. Both techniques require essentially the same facilities for rolling, turning, machining, welding, and heat-treating operations. All required equipment, except heat-treat facilities, is available at existing plants.

Segmented engine cases may be transported from fabrication facilities by truck or rail to new or existing propellant plants. Unitized cases will require water shipment; commercial barges will be adequate.

In the early phases of the development program no one existing plant will have the capability to accomplish all required operations; several plants may have to be used. Facility deficiencies at the most capable plants may be supplemented to provide integrated facilities for the continuing program. As production rates beyond the capacity of any one plant are exceeded, other sources may be established to accommodate these rates. By the program outlined here, case manufacturing can be accomplished without delay to the program. If new facilities were to be constructed, lead times of one to two years would be required. Also, a new production organization would be needed, resulting in manpower, housing, and support problems. Costs for new facilities would greatly exceed those for supplementing existing facilities.

The size and weight of the cases considered for this study do not create a significant problem in building heights, crane capacities, or general handling problems within the plant. Buildings required for the fabrication of the cases will have a minimum of 25- to 30-foot height under the crane hook. Twenty-five-ton cranes will be satisfactory for the segmented design, but a minimum of 50 tons should be provided for handling the unitized cases. These capacities can best be provided by multiple cranes which allow for lifting at both ends, differential lifts, and repositioning of pieces.

Cleanliness will be a stringent requirement of the work area. This will be especially true of areas where welding is accomplished. Ventilation and dust control will be required to provide the environment necessary for high-quality welds. Extensive cleaning, painting, and other protective coating processes will be required to insure clean surfaces for welding and protected surfaces for storage and transportation. Internal tank surfaces will be thoroughly cleaned and coated with rust preventative and external surfaces prime coated or finish painted prior to shipment. End closures and protective covers would further protect the units during shipment.

The required machine tools such as boring mills, drilling machines, and lathes are of sizes common to industry. Considerable special tooling will be required to position welders and work pieces for the welding operations. Preheat and post-heat devices of the flame, resistance, or induction type will be mounted on this same tooling.

While much of the equipment except the special tooling is available at existing plants, there is a lack of suitable heat-treat facilities. Numerous present furnaces capable of handling or being converted to handle air quenching steels can accommodate work pieces of the segment size. New facilities would be required, however, to provide furnaces for the liquid quenching steels. Several planned installations or conversions are under consideration and should be available without delay to the development program. Other new furnaces can be provided for the production program.

Figures VI-1 and -2 show typical arrangements of manufacturing areas for the segmented and unitized cases. These layouts show only the direct manufacturing area devoted to case fabrication and do not show the office, tooling, warehouse, and other support facilities. Jig and position requirements (Appendix 2, Tables AVI-1 and -3) and major capital equipment lists (Appendix 2, Tables AVI-2 and -4) accompany these layouts and define the items shown. These are schematic typical layouts only and actual plants would probably have the facilities divided among several buildings. Layouts, equipment lists, and position requirements are based on a one-per-month rate for the C-3 configurations.

NOZZLES

Facilities for nozzle manufacture consist primarily of the machine tools required to fabricate steel ring sections, flanges, and graphite throat liners. Filament-winding forms, for layup and forming of the exit cones, are tooling items designed specifically for each configuration. Heating and pressure application devices will be incorporated into the tooling so that requirements for large ovens or presses will be eliminated. High-bay crane-covered area presently available

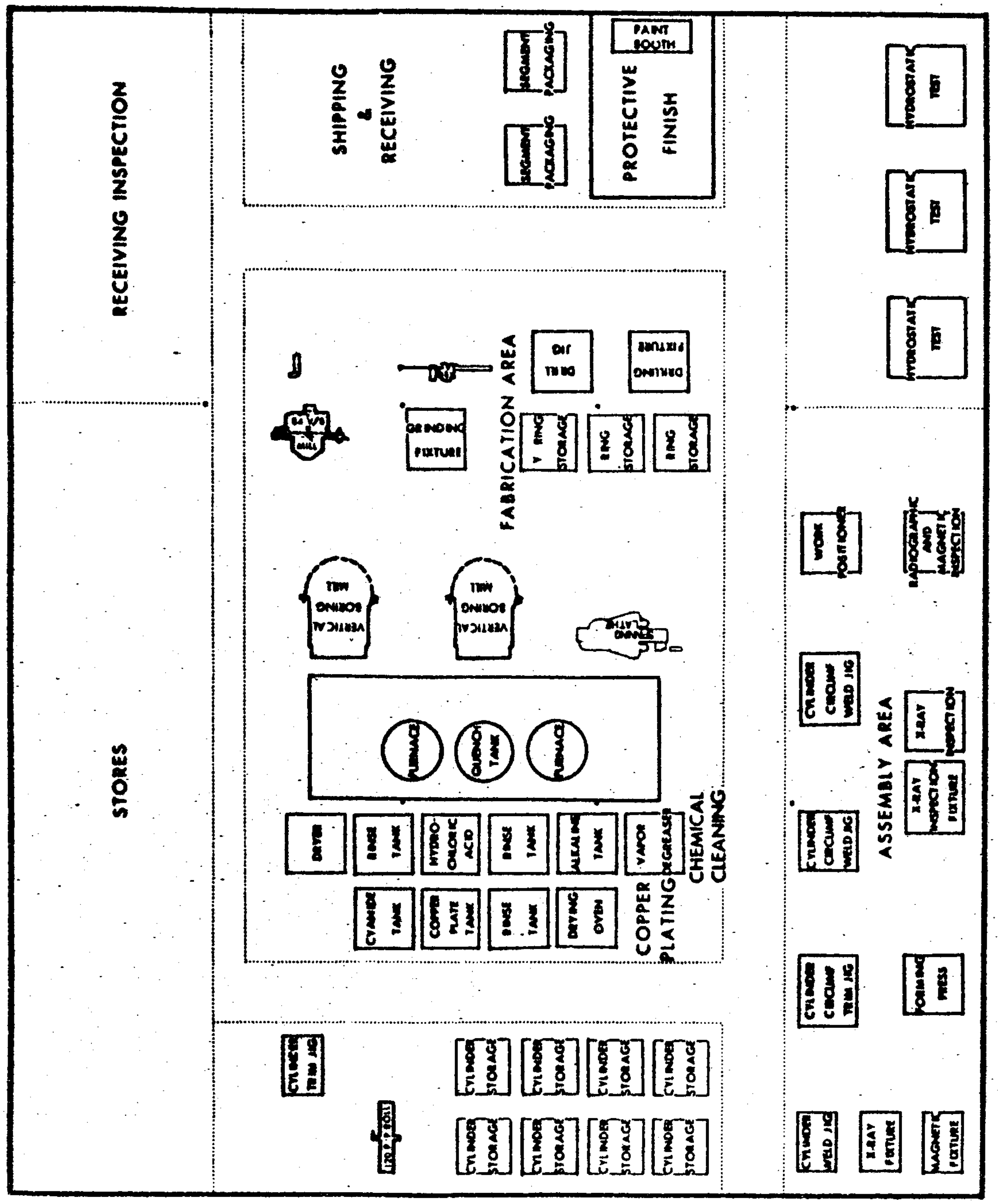


Fig. VI-1 SOLID PROPELLANT BOOSTER CASES
VEHICLE 3-SC4

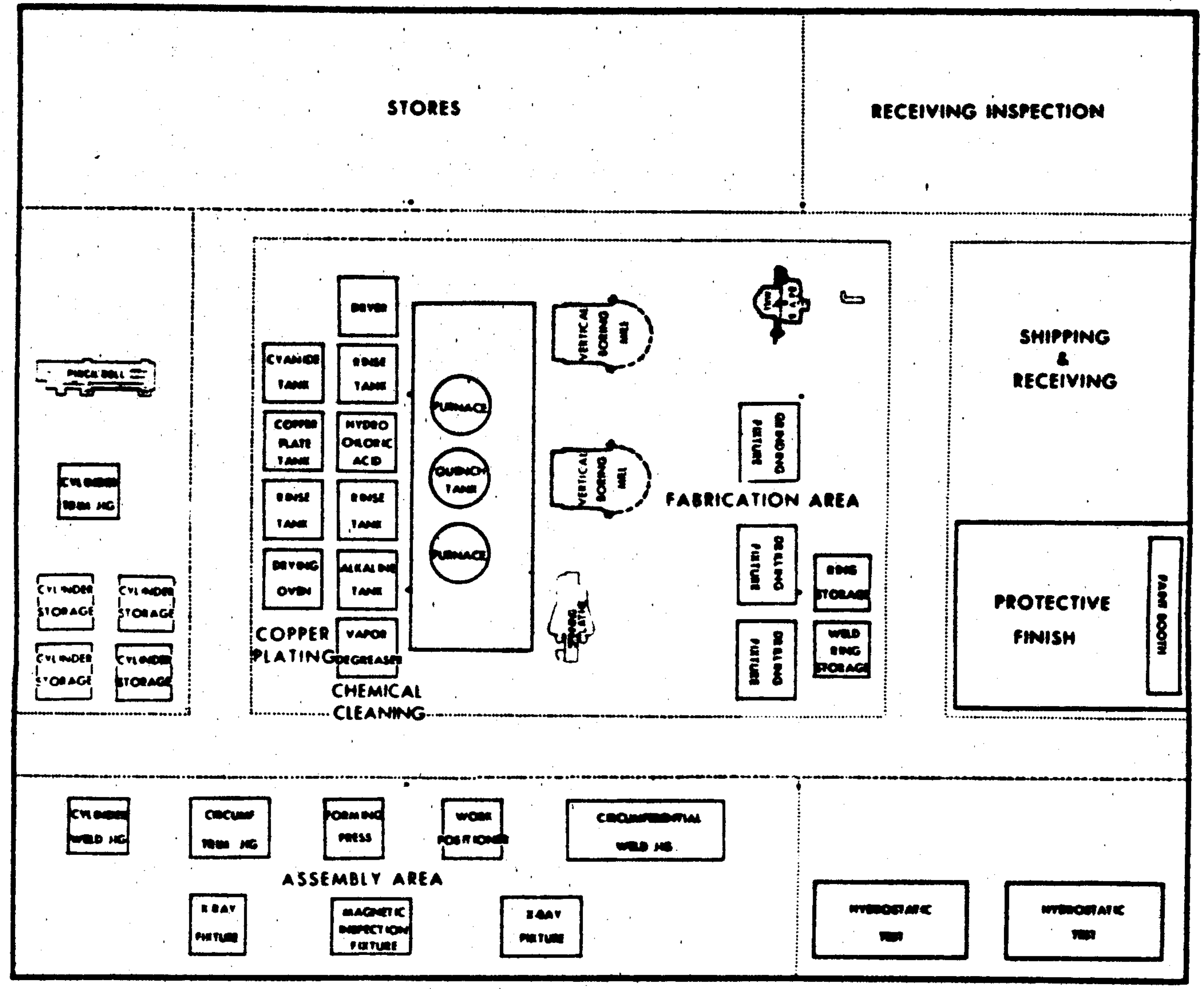


Fig. VI-2 SOLID PROPELLANT BOOSTER CASES
VEHICLE 3-UC4

throughout the aircraft and other fabricating industries will be satisfactory to accommodate these manufacturing processes.

All nozzles except those for Nova are small enough to be transported by rail or highway. The larger nozzles will require water shipment; the weights involved create no problem. Except for the large Nova nozzle no problem exists for any of the available facilities and even the Nova nozzle presents less of a transportation problem than do the Nova payload and upper stages.

INTERSTAGE STRUCTURE AND FINS

The capability to manufacture the interstage structure and fins for the study vehicles is available; these items are similar to airplane structures. Again, available crane-covered high-bay area and the usual fabricating equipment will be adequate. The smaller of these items may be shipped by rail or highway but larger items will require water shipment. Facilities for the fabrication of water-shipped items will be limited to those having access to water transportation. In some cases the items may be shipped in sections by rail or highway. Final assembly or reassembly may then be accomplished at the launch site.

ACCESSORY EQUIPMENT

No facilities problem is anticipated with accessory or auxiliary items. The size, weight, and nature of these items are within the capability of the present facilities. Electronic, electrical, hydraulic, and other component manufacturing facilities are readily available; and all of these items can be shipped by rail or highway.

2. PROPELLANT MANUFACTURING FACILITIES

GENERAL

Current methods of propellant manufacture can be employed in manufacturing the large segmented and unitized engines. Changes will be in the size of the facilities and the handling methods and equipment to accommodate the larger dimensions and heavier weights.

A survey of the major propellant manufacturers shows that existing facilities will be adequate for development programs on the segmented study engines. These plants possess or have under construction the facilities to handle at least 120-inch diameter segments. Minor supplements to this capability will allow these plants to handle 160-inch diameter segments. No extensive transportation difficulties exist to prevent shipment of segments of this size. These facilities, therefore, may readily be used to develop the segmented engines and to provide an initial increment of production for the programs.

It does not appear feasible to consider these existing facilities for continued use and further expansion to accommodate the full, operational segmented programs. The curves on Figure VI-3 show the requirements of the various programs in comparison to the total mixer capacity of the propellant industry and for a typical large plant. This chart does not take into consideration that part of this capacity is being used on other developmental and production programs. In addition, support facilities such as casting, curing, case preparation, and grain inspection are not equal to the mixing capacity, especially for the large engines. These conditions and the long transportation distances indicate that a new plant should be constructed for the operational program for segmented engines.

The survey of existing propellant manufacturing facilities showed that no significant capability is available to develop or produce large unitized engines. Additional facilities required to supplement these plants would be extremely expensive and limited to an on-site development program. None of the plants is situated in a manner to provide a reasonable solution to the transportation of these engines to the launch site. It will, therefore, be necessary to construct new facilities for both the development and production of the unitized engines. The availability of these facilities, however, will not be critical to the program. In fact, the use of these facilities during the development program will provide a shakedown for the personnel and equipment which could prevent delays later in the program.

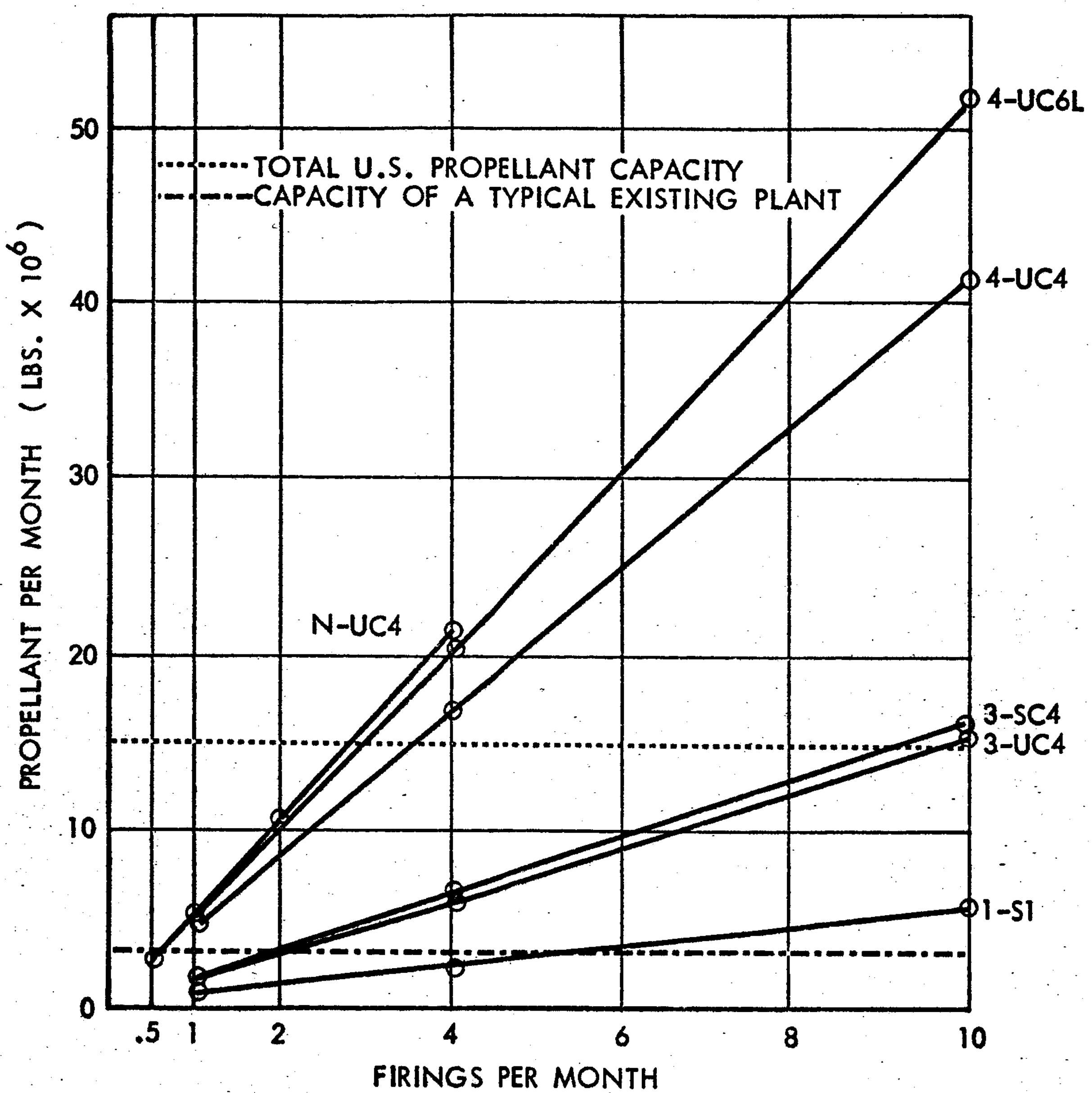


Fig. VI-3 SOLID PROPELLANT PROCESSING CAPACITY VS. REQUIREMENTS

Raw materials for propellant manufacture will not present a problem in the early phases of either the segmented or unitized programs. If the higher production rates outlined in this study are attained, additional facilities will be required to provide the large quantities of some of the materials needed. These facilities could be provided by private industry.

The material of most concern is ammonium perchlorate. The present national capacity is 20,000 tons per year. The presently installed mixer capacity of the solid-propellant industry could use 60,000 tons per year. Requirements for the programs of this study range from 2400 tons per year to 200,000 tons per year. While it is unlikely that the higher rates will become a reality, it is significant that at a one-per-month firing rate the C-4 configuration would require about 20,000 tons per year, or the present national capacity. Stockpiling of present excess capacity would preclude any shortage early in the program and the construction of additional capacity, available in about 18 months, would provide for the increased requirement.

Since it has been determined that new propellant manufacturing facilities will be required for either the segmented or unitized operational programs and the unitized development program, a detailed discussion is provided in Appendix 2, Section IV, to further define these facility requirements. The propellant manufacturing facility will provide all of the operations necessary to process engine cases through all required steps. This plant will be divided into inert and hazardous areas for these two classes of operations. This plant may be near the launch complex or a considerable distance away. The transportation scheme for finished engine cases will vary with distance and transportation conditions. Water shipment will be required for the large unitized engines and would be the preferred method for transporting segments. For this study, the ideal situation (propellant plant integrated with the launch complex) is shown. The first part of the following discussion describes the facilities common to both the segmented and unitized plant. The latter parts of the discussion describe the specific facilities required for the segmented or unitized designs.

C. ASSEMBLY AND TEST FACILITIES

1. NONHAZARDOUS

This group of facilities will be for subassembly and checkout of components, receival and inspection of components and subassemblies, and compatibility and functional testing of all mechanical and electrical parts.

FIRST STAGE SUBASSEMBLIES FACILITY

Functions pertaining to receival, subassembly, and checkout of all nonhazardous first stage components are performed at this facility. Vehicle design differences between the single motor and clustered motor first stages require that two different facilities be designed to handle the two situations.

Single-Motor First Stage (1-S1) (Appendix 2, Figure AVI-10)

This facility is capable of performing four functions: 1) receival and inspection (R&I) of the nozzles and shipping to final assembly area, 2) R&I and assembly of the skirt and TVC components, 3) assembly of the 1-2 interstage, and 4) assembly of the vehicle support structure and installation on the pallet.

Function 1) involves the receival, inspection and storage of the first-stage nozzle. Whenever a pallet leaves this facility, a nozzle must be taken from storage and transported to the final assembly area.

Function 2) is the receival of the components and the assembly of the skirt and TVC. The skirt is first assembled and then the TVC is attached around the inside periphery of the skirt. The completed assembly is then sent to the integration checkout and final subassembly facility for the vehicle compatibility check.

The components necessary for the assembly of the 1-2 interstage are received and stored. The assembly of these components into the interstage and the shipping of the interstage to the integration checkout and final subassembly facility completes function 3).

Function 4) involves the assembly and positioning of the first stage support ring on the pallet. Two adjacent fins are then attached to this support. The stabilizers for the other two fins are installed and the fins are placed on the pallet but not put in place. The pallet is then transported to the final assembly area.

All four functions are done sequentially and therefore may be done by one crew.

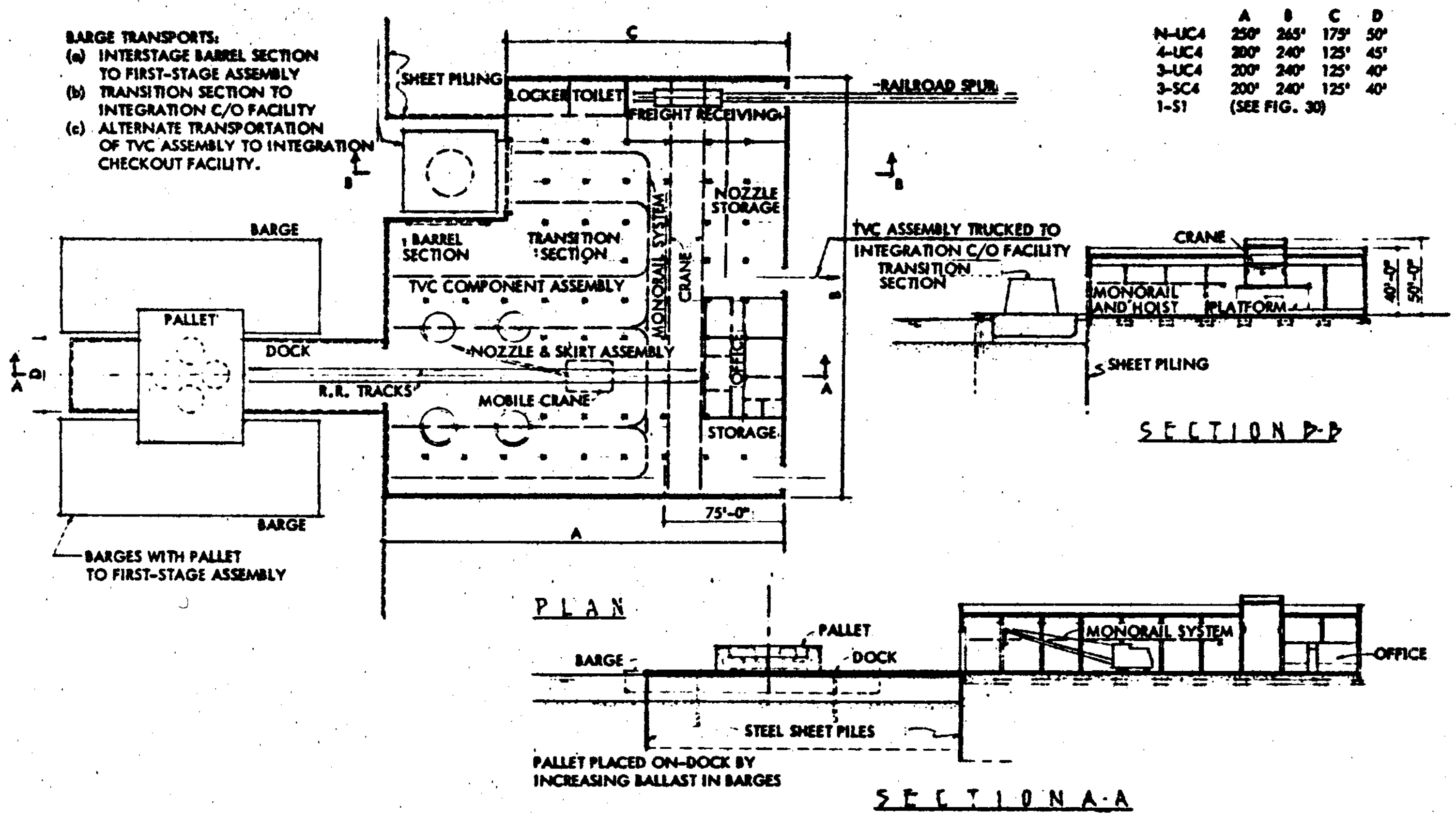
Cluster Motor First Stages (Figure VI-4)

The five functions performed in this facility are: 1) R&I of first stage interstage structural pieces, 2) nozzle and skirt R&I and assembly, 3) TVC components R&I, assembly (minus Freon tank), and checkout, 4) R&I and subassemblies of 1-2 interstage, and 5) assembly of the first stage support system.

Function 1) involves the receiving and storing of the structural pieces used to tie the first stage skirts together. These pieces are used during the function 5) operation.

Function 2) involves assembling the necessary components to make a skirt and installing a nozzle inside the skirt. Since in the completed vehicle there is no structural tie between the skirt and the nozzle a temporary support is used holding the nozzle near the throat. This support not only holds the nozzle in the correct vertical position but also prevents the nozzle from moving horizontally within the skirt.

Function 3) is the assembly and checkout of the linkages and tanks for the TVC system. Upon completion, this assembly is sent to the integrational checkout facility for compatibility testing. In the larger payload vehicles any tankage which, in the assembled vehicle, is located above the top of the skirt is not included in this assembly. These tanks, which in all cases includes the Freon tank, are sent to the first-stage assembly area for installation at the proper time.



	A	B	C	D
N-UC4	250'	265'	175'	50'
4-UC4	200'	240'	125'	45'
3-UC4	200'	240'	125'	40'
3-SC4	200'	240'	125'	40'
1-S1	(SEE FIG. 30)			

Fig. VI-4 FIRST-STAGE ASSEMBLY
FOR CLUSTERED FIRST-STAGE VEHICLES

Function 4) is the R&I of the components and their assembly into 1-2 interstage subassemblies. The barrel sections and their connecting truss structures are assembled such that the barrel sections can be individually installed on the motors and tied together with a minimum number of operations at the first-stage assembly area. The transition section of the interstage is assembled and sent to the interstage mating facility upon completion.

Function 5) is the clustering of the nozzle and skirt assemblies on a pallet to form a support for the motors. The skirts are tied together by means of the interstage ties and the TVC assembly is installed in the center of the cluster. If the vehicle has fins they are installed at this location. The pallet is taken from this area to the first-stage assembly area for installation of the solid motors.

UPPER-STAGE R&I FACILITY (Appendix 2, Figure AVI-11)

The assembled second stage and the payload are received (separately) on barges at this facility. A checkout is performed on each to insure functional compatibility of all parts within the stage. The stage is not removed from the barge during the checkout operation. Inspection of the two stages need not be done concurrently. After both stages have checked out, they are moved on their carrier barges to the intergrational checkout facility.

INTERSTAGE ASSEMBLY FACILITY (Appendix 2, Figure AVI-12)

The two payload-interstage components are received, inspected, and then assembled. After assembly the interstage is checked out and then sent to the integrational checkout facility for compatibility checks with the other vehicle electrical and mechanical components.

INTEGRATIONAL CHECKOUT FACILITY (Figure VI-5)

All working components are brought to the integrational checkout area for a complete end-to-end functional and compatibility check. The payload and second

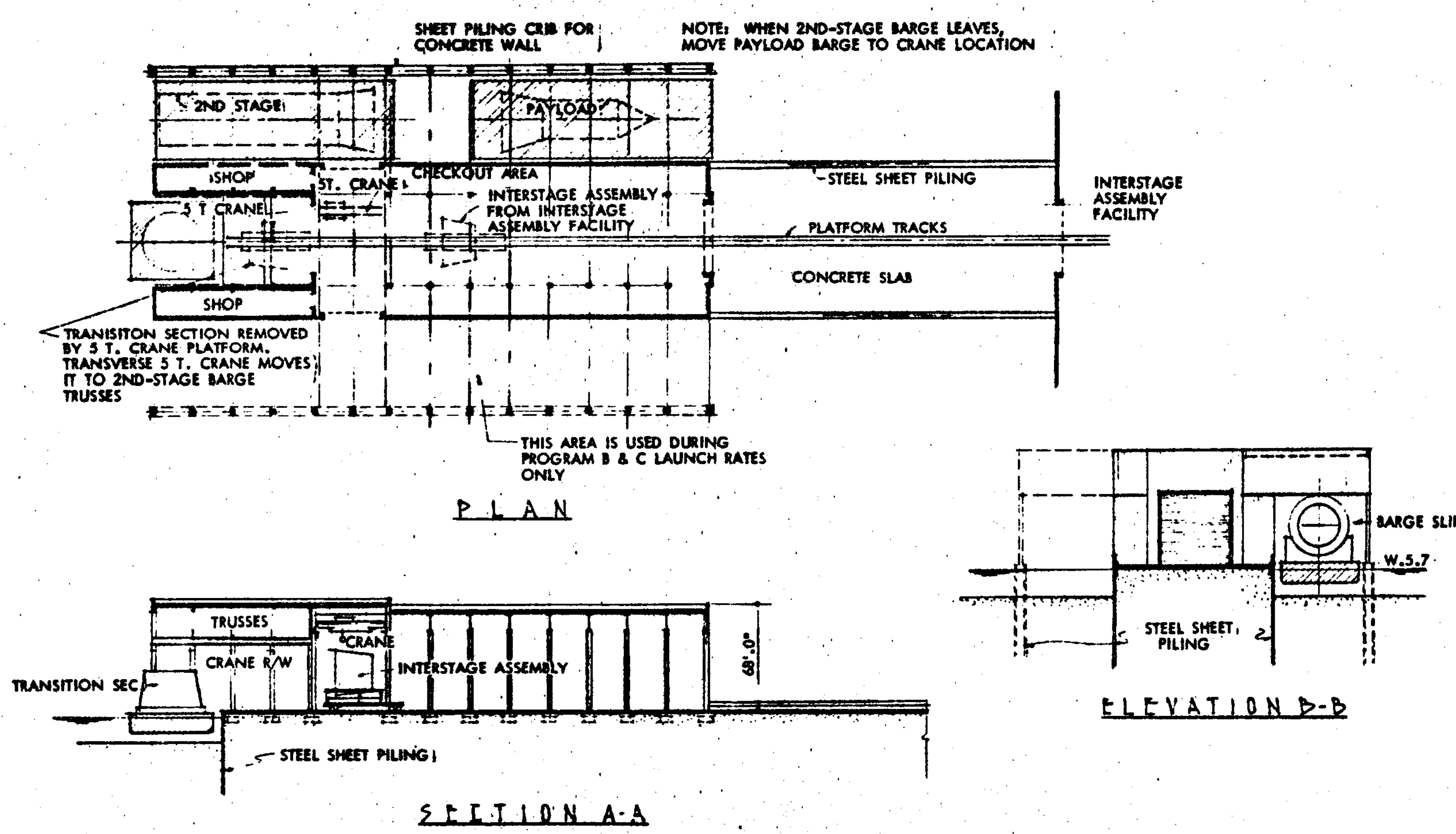


Fig. VI-5 INTEGRATIONAL CHECKOUT FACILITY stage arrive on barges in a horizontal position and remain on the barges throughout the operation. All other components will arrive via land transportation.

After completion of the checkout, the TVC assembly (clustered motor configuration only) is sent back to the first-stage subassemblies facility for installation in the skirt assembly. The 1-S1 TVC assembly is already attached to the skirt and is sent directly to the final assembly facility.

The transition section of the 1-2 interstage is brought into the area and mated to the second stage. The two-payload interstage and the payload are then mated. After mating, the second stage and payload are barged to the final assembly facility for installation.

Under the Program "A" launch rates, both the checkout and mating functions are done by the same crew, but for Programs "B" and "C", the mating functions are done on one vehicle by one crew while another crew is accomplishing the checkout on a second vehicle.

PALLET RECONDITIONING FACILITY (Appendix 2, Figure AVI-13)

After launch, the vehicle pallet is transported back to a pallet reconditioning facility in the nonhazardous area. Here any reworking necessary due to launch damage is accomplished. After dropping off the damaged pallet the barges pick up a reconditioned pallet and move it to the first-stage subassemblies facility. It is not known what effects the action of such an intense heat for a very short period of time (2-5 seconds) will have on the pallet structure. Therefore, it is impossible to detail the operations which must take place and consequently the amount of time that these operations will take. For the purposes of costing, it was assumed that pallet reconditioning could be accomplished in one week.

2. HAZARDOUS

This group includes the final assembly area and the solid-motor static-test facility, the latter being used for a short time during the development program only.

FINAL ASSEMBLY AREA

The final assembly of the vehicle is broken down into two distinct operations: 1) the actual assembly of the vehicle first stage, and 2) the mating of the second stage to the first stage and the payload to the mated second and first stages. First-stage assembly starts with the receival of individual segments or unitized motors and ends when the vehicle is ready for the installation of the second stage. Three slightly different concepts for this assembly, necessitated by vehicle design differences and resulting in three different assembly times, will serve to describe this operation for all five vehicle configurations. The concept for the second operation, the installation of the second stage and payload, is identical for all five vehicles, however the location at which this operation is performed is dependent upon the vehicle configuration and the program launch rate.

1-S1 Vehicle

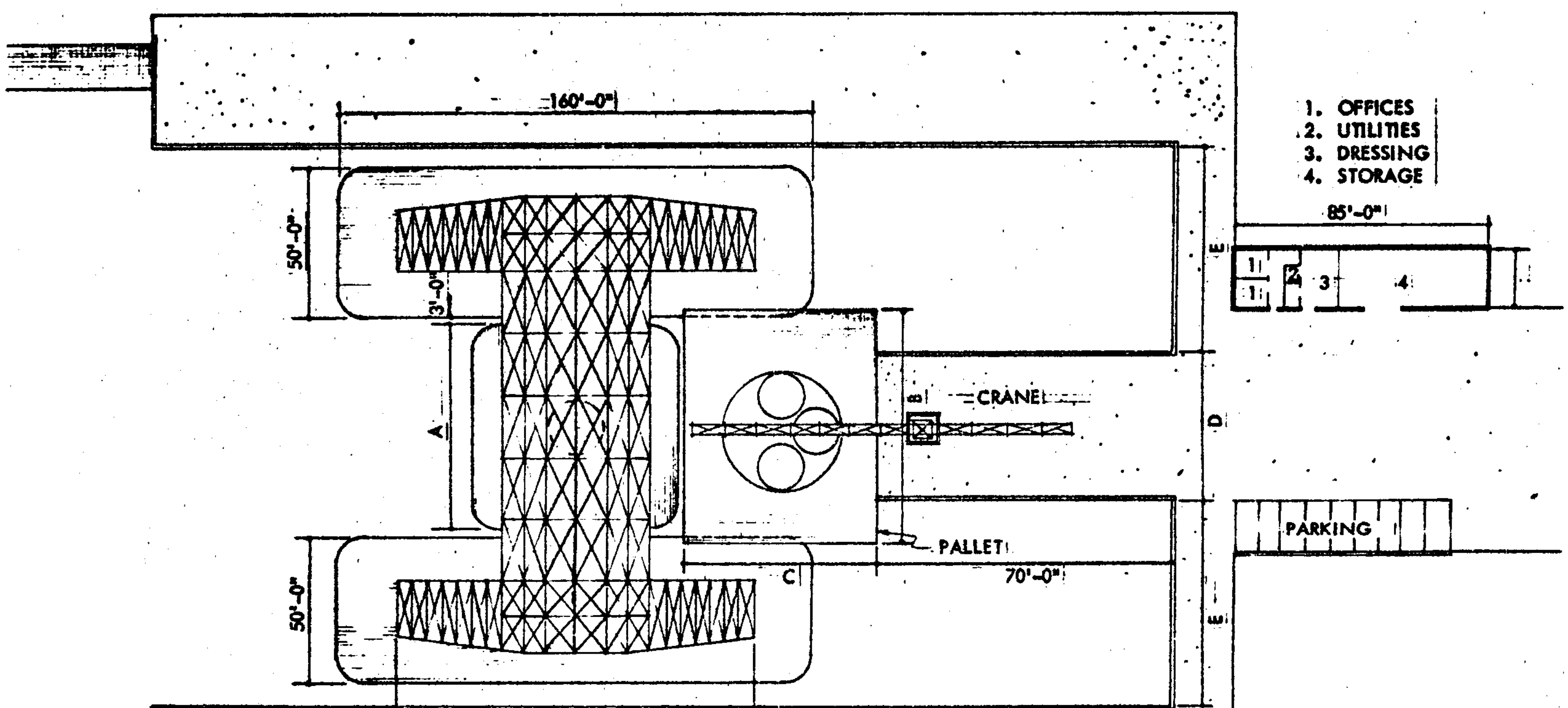
The first stage of this vehicle cannot be assembled from the base up as can the other vehicles because it is not skirt supported. The pallet arrives at a first-stage assembly facility (Appendix 2, Figures AVI-14 and -15) with the support ring in place. The nozzle is set in position beneath the support ring and held by a temporary jacking fixture. The aft segment is then lowered into place and connected to the support ring. The nozzle is jacked into position and bolted to the aft segment. The skirt containing the TVC assembly is set on the pallet and is broken open about the hinge so that the assembly resembles an open clam shell. The assembly is set around the nozzle and the two hinged sections brought together and connected. The two fins which are still on the pallet are then connected to the vehicle. Installation of the remaining three segments and the pressure checking of the joints completes the assembly operation. From here the pallet is taken to the second-stage installation facility (Appendix 2, Figures AVI-16 and -17) where the second stage and then the payload are mated to the vehicle.

A fixed land-based gantry is used at the first-stage assembly facility as crane movement in only one direction is necessary. The crane picks up a segment off a barge moored beside the pallet and sets it in place on the pallet. A light capacity stationary hammerhead crane located adjacent to the pallet provides secondary lift capacity during assembly. The crane support structure has an elevator in it for vertical movement of personnel. A semicircular section of the work platform which is hinged to the crane support structure is lowered into a horizontal position when needed. The light crane then picks up the other half of the platform and the two sections are connected together. This then provides the working platform completely encircling the vehicle which is used for connecting two segments together.

The crane at the second-stage installation facility, a taller, fixed, land-based gantry (Appendix 2, Figure AVI-17) lifts the second stage (or payload) off the barge, which is moored beside the ballet, and places it on the vehicle. A vertical access tower, located adjacent to the pallet and attached to the top of the crane houses an elevator and also serves as support for the cantilevered work platforms. An annular work platform is picked up by the gantry, placed over the vehicle, lowered into position, and held there. The access link, which is hinged to the tower, is lowered into a horizontal position and connected to the annular platform. Cables connected to the tower are brought out and connected to the annular platform. The gantry then releases its hold on the platform. Work platforms are required only at the two interstage levels.

3-SC4 Vehicle

As with all the skirt-supported vehicles, the 3-SC4 first stage can be assembled from the ground up. The pallet arrives at the first-stage assembly facility (Figures VI-6 and -7) with the skirt assemblies clustered and tied together. The first aft segment is lowered onto and connected to the skirt. The nozzle is jacked into position and bolted to the segment. The remaining aft segments are then placed, and their nozzles installed. Three of the motors are built up



	A	B	C	D	E
N-UC4	70'	80'	65'	50'	70'
4-UC4	70'	75'	60'	45'	70'
3-UC4	50'	70'	55'	40'	55'
3-SC4	40'	70'	55'	40'	55'

CRANE CAPACITIES (TONS)
N-UC4 - 750
4-UC4 - 600
3-UC4 - 225
3-SC4 - 100

Fig. VI-6 FIRST-STAGE ASSEMBLY FACILITY

	A	B
N-UC4	105'	125'
4-UC4	115'	135'
3-UC4	65'	85'
3-SC4	65'	85'

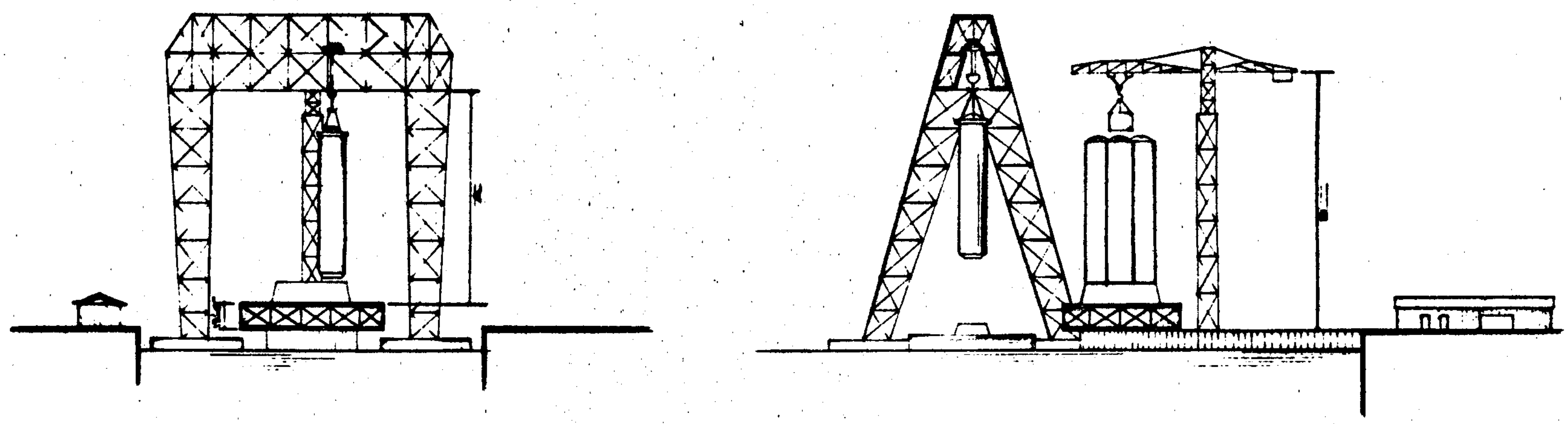


Fig. VI-7 FIRST-STAGE ASSEMBLY FACILITY

segment by segment and, as each motor is completed, a barrel section of the 1-2 interstage is connected to it. After the third barrel section is in place, the three are structurally tied to each other. The Freon tank with its support structure attached to it is put in place and tied to the three barrel sections. Completion of the fourth motor and installation of its barrel section of the interstage completes the assembly operation. The pallet is then moved to the second-stage installation facility where installation of the second stage and then the payload is accomplished.

Because crane movement in two directions is necessary for first-stage assembly of all four clustered configurations, a short span floating gantry (Figures VI-6 and -7) is utilized. The gantry straddles the motor transport barge, picks up the motor, and is moved forward to the pad by means of winch and cable. The same type of hammerhead crane and work platform system described for the 1-S1 first-stage assembly facility is also used here.

3-UC4, 4-UC4, and N-UC4 Vehicles

This sequence of operations is essentially the same as for the 3-SC4 except that, because the motors are unitized, they are installed as a unit one at a time. As each barrel section of the interstage is installed, it is structurally connected to the installed sections. After the third motor is installed, the helium and Freon tankage are installed. The installation of the fourth motor and its barrel section completes the assembly operations.

Under Program "A", launch rates, both the assembly operations and the installation of the second stage and then the payload are done at a single location, the final assembly facility (Figures VI-8 and -9). When Programs "B" or "C" are considered,then two separate areas, a first-stage assembly facility (Figures VI-6 and -7) and a second-stage installation facility (Appendix 2, Figures AVI-16 and -17), are utilized; thus creating the same situation as exists under all three program launch rates for the segmented vehicles.

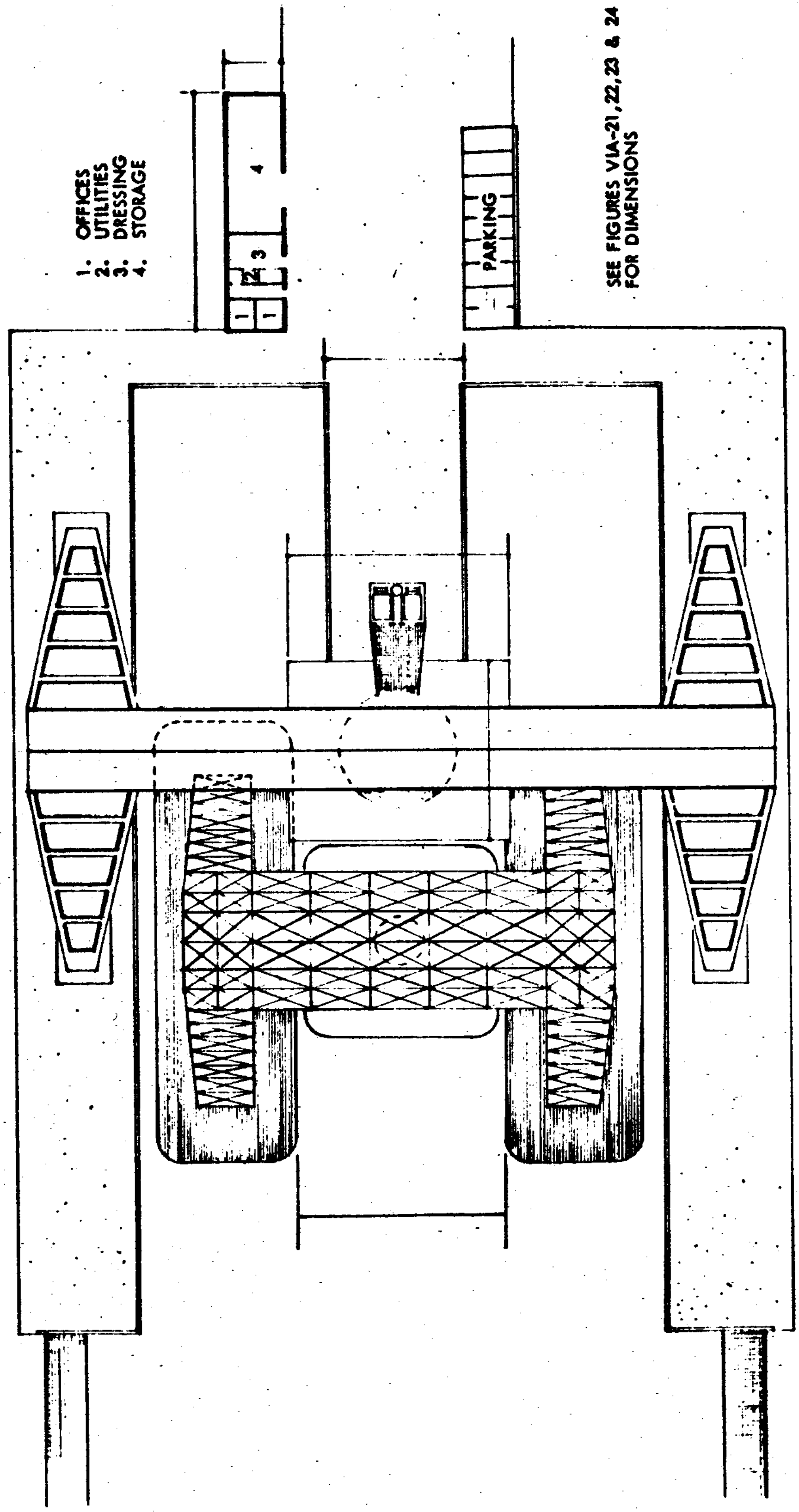
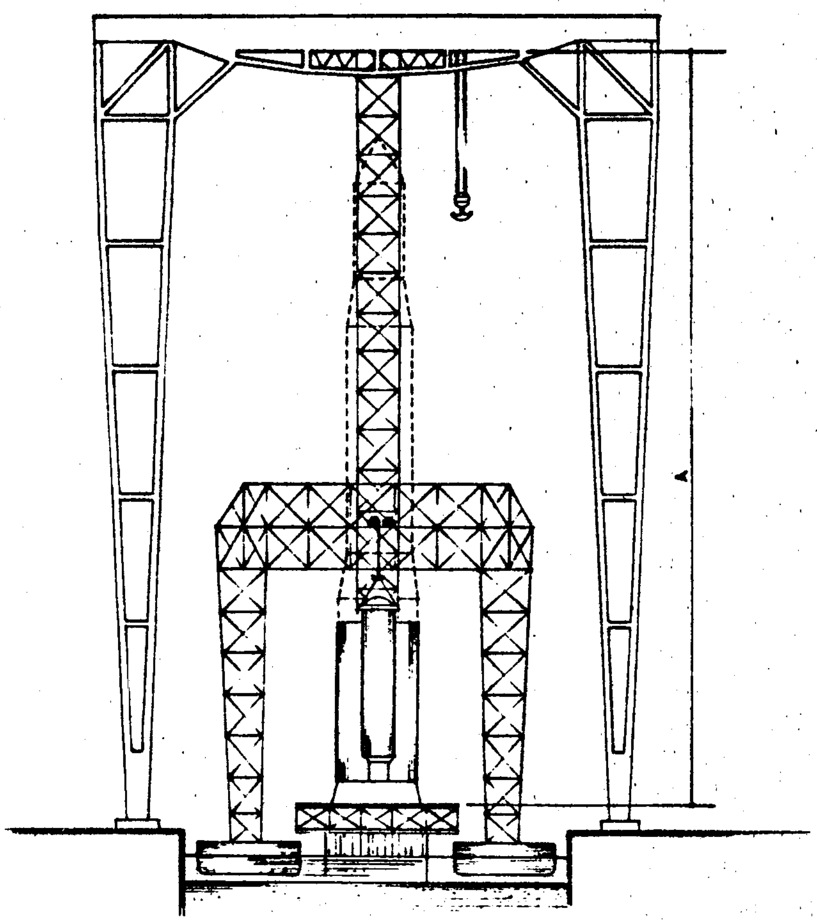


Fig. VI-8 FINAL ASSEMBLY FACILITY



	A	B
N-UC4	360'	295'
4-UC4	300'	315'
3-UC4	225'	240'
3-SC4	225'	240'
1-SC1	210'	230'

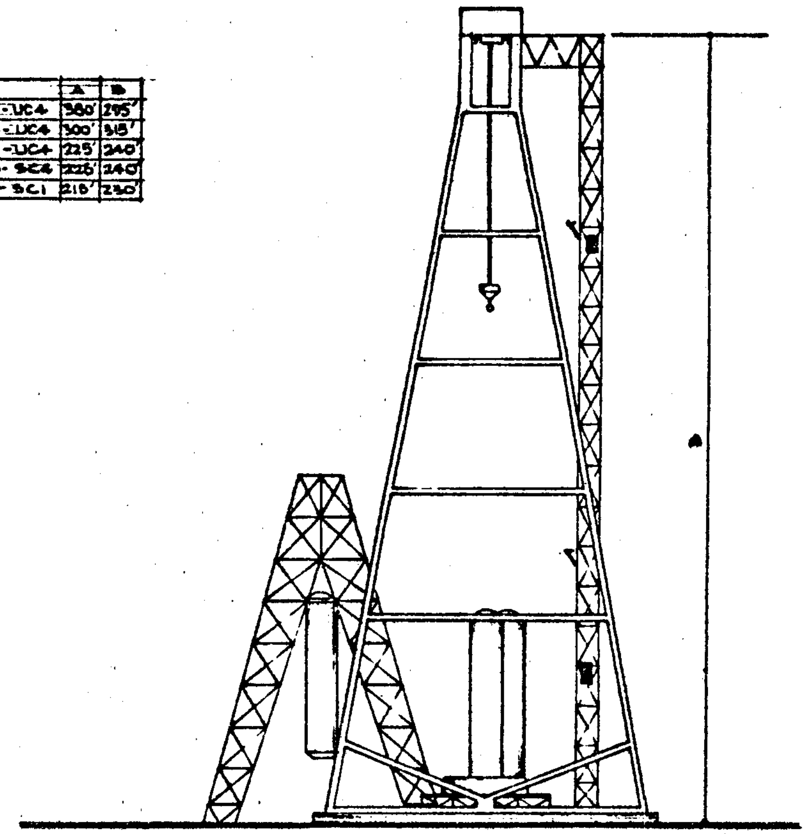


Fig. VI-9 FINAL ASSEMBLY FACILITY

STATIC TEST FACILITY (Appendix 2, Figure AVI-18)

Static testing of the solid motors will be done in a vertical position aft end up at this location. This testing is done only during the development period and therefore the test area can be located very close to the operational launch area. The process of manufacturing the solid motors for test has been described. The completed motor or segments are brought to the first-stage assembly facility on a transport barge. There segments are vertically assembled into a complete motor, aft end up, and the nozzle installed. This is done on a special transport barge which is equipped with a set of rails. The unitized motor is already on the special barge so that nozzle installation only need be done. A motor transporter similar in design to the motor rotator used at the finishing and inspection facility is lifted onto the barge and set on the rails. The motor and motor transporter are connected together and tied down and the barge is taken to the static test facility. The barge is positioned in the mooring slip and sunk. Jacks raise the motor clear of the barge supports and the tie-downs are removed. The motor is taken to the static test stand and lowered onto it. Structural steel framing is used to tie the motor to the concrete and earth reventment. Test equipment is connected to the motor and all personnel are evacuated from the area for the test. Monitor and control of the test is done from the small control house located in the revetment.

D. LAUNCH FACILITIES

Facilities necessary to perform functions done after final assembly up to actual launch will be in this area. This includes the checkout and launch facilities and the launch control blockhouse.

1. CHECKOUT AND LAUNCH AREA

The completely assembled vehicle and pallet are transported to the checkout and launch area for the prelaunch preparations and launch. The functions performed in this area are broken down into two classes of operations.

The first class determines whether or not all the components of the assembled vehicle are still operating and compatible with each other. This is essentially the same checkout as was performed on these components in the integrational checkout facility prior to their assembly. The second class covers all operations performed subsequent to the above up to and including launch.

Both classes of operations are performed at the same physical location (Appendix 2, Figures AVI-19 and -20) for the Program "A" launch rates. For Programs "B" and "C", each class of operations is accomplished at a separate location in order to reduce the number of launch areas.

A combination crane-elevator tower similar to that used at the first-stage assembly facility and an umbilical tower are required to service and checkout the vehicle. For Program "A", the checkout and test equipment is located in the launch control blockhouse. This one set of equipment is utilized during both classes of operations. Launch schedules "B" and "C" require that two sets of equipment be utilized, one at the launch control blockhouse for the second class of operations and one at the intravehicle checkout facility (Appendix 2, Figures AVI-21 and -22) for the first class of operations. The latter set will be housed in a concrete block structure located close to the vehicle.

2. LAUNCH CONTROL BLOCKHOUSE

This structure houses the equipment necessary to accomplish the first and/or the second class of operations as described in the previous section. It is a hardened structure and similar in design to those in use at Cape Canaveral for the Saturn (Complex #34), Titan, and Atlas programs. One blockhouse is large enough to house the equipment necessary to control two launch areas. This means that for the Program "A" launch rates, excess capacity exists because only one launch area is required.

E. REQUIREMENTS

Facilities requirements to accommodate the three program launch rates for each vehicle are tabulated in Appendix 2, Tables AVI-5 through -14. Tabulated values are on the basis of the number of facilities required for those where detailed drawings have been made or by square footage for those which have been described but not shown.

In the case of the assembly and launch facilities, the numbers are "ideal" as no provision has been made for the rework necessary when a major component has been found to be defective during the final assembly checkout and must be replaced. Some special facility or facilities must be provided to de-assemble the vehicle, replace the faulty component, and reassemble the vehicle. If no such facility is provided, rework either means a sliding of the program schedule or storage of the rejected vehicle.

The amount of rework will depend on the reliabilities attained in the various components and subsystems by the time the peak production rate is reached.

F. BASE DESIGNS

Base layouts for the Program "A" launch rates for the various vehicles are shown in Appendix 2, Figures AVI-22 through -26. These layouts are "ideal" in two respects: they are not sited to a specific location and, no provision has been made for rework on vehicles that are rejected during the final assembly and checkout operations because of a malfunctioning component. The following ground rules or criteria were used in establishing the layouts.

1) All launches will be made from shore out over the ocean.
2) All launch areas approximately equidistant from the ocean.
3) A flat, sea-level topography which is suitable for a canal network was assumed.
4) Solid propellant manufacturing facilities for the unitized configurations will be located adjacent to the assembly and launch facilities. Segmented motor

production may be located adjacent to the assembly and launch operations, but may also be anywhere along a connecting inland waterway such as the Intracoastal Waterway.

5) Layouts were made so as to utilize both the minimum amount of ocean frontage and total acreage.

6) Acoustical criteria were the basis for determining base boundaries. All land areas where a noise level greater than 125 db would be experienced during launch would have to be under control of the governing agency of the program. Within the base, no personnel would be allowed in any area (with the exception of the personnel in the launch control blockhouse) where they would be subjected to an outside noise level of 140 db or greater. All personnel who might be subjected to noise levels of 130 db or above will be provided ear plugs, so that operations in that area may continue during launch.

Source pressure levels, in db, were estimated by the expression

$$PWL = 78 + 13.5\ (\log_{10} 21.8\ FIsp)$$

where:

PWL= source sound pressure level in db of one motor

F = thrust in pounds of one motor

Isp = specific impulse in seconds

The source sound pressure level of the entire vehicle, OAPWL, was determined by

$$OAPWL = PWL + 10 \log_{10} X$$

where:

X = number of first stage motors

Once the source noise level was determined the distances to the criteria noise levels were established by use of the expression

$$SPL = OAPWL - (10 \log_{10} A) + D - F$$

where:

SPL = criteria sound pressure level in db

$A = 4\pi R^2$, spherical sound divergence relationship where R = distance from source to the criteria sound pressure level.

D = Directivity index, the difference in db between the true SPL at a given angle from the vehicle and the calculated space average SPL at the same distance.

F = absorption of sound in addition to the spherical attenuation factor A, at distance R, in db. This absorption is dependent upon frequency.

The following table was developed using the method outlined above.

Vehicle	Distance to Criteria Level (Ft.)		
	125 db	130 db	140 db
1-S1	5,700	3,200	1,000
3-SC4	9,500	5,300	1,800
3-UC4	9,500	5,300	1,800
4-UC4	14,800	8,500	2,700
N-UC4	19,800	11,100	3,600

7) Spacing for those facilities classified as hazardous was determined by the use of extrapolations of the Quantity-Distance Standards as outlined in Air Force T. O. 11C-1-6 for Class (or Group) 9 explosive, however, it is possible that the particular solid motors involved could obtain a Class 2 rating after a series of tests were made on the actual motor. Since a finished motor is necessary for actual classification, it is safest to assume that the more hazardous rating will apply.

The curves of Figure VI-10, which are based on T. O. 11C-1-6, were used in this study. Hazardous facilities are spaced on the basis of "intraline separations" distance. The nonhazardous facilities are located no closer to a hazardous facility than allowed by the "inside inhabited building" distances. The Air Force distinguishes between buildings inside the reservation or base boundaries and those outside the base which may not be under Government control. Base boundaries as established by acoustic criteria have been altered where necessary so that "outside inhabited building" distances can be maintained from hazardous facilities.

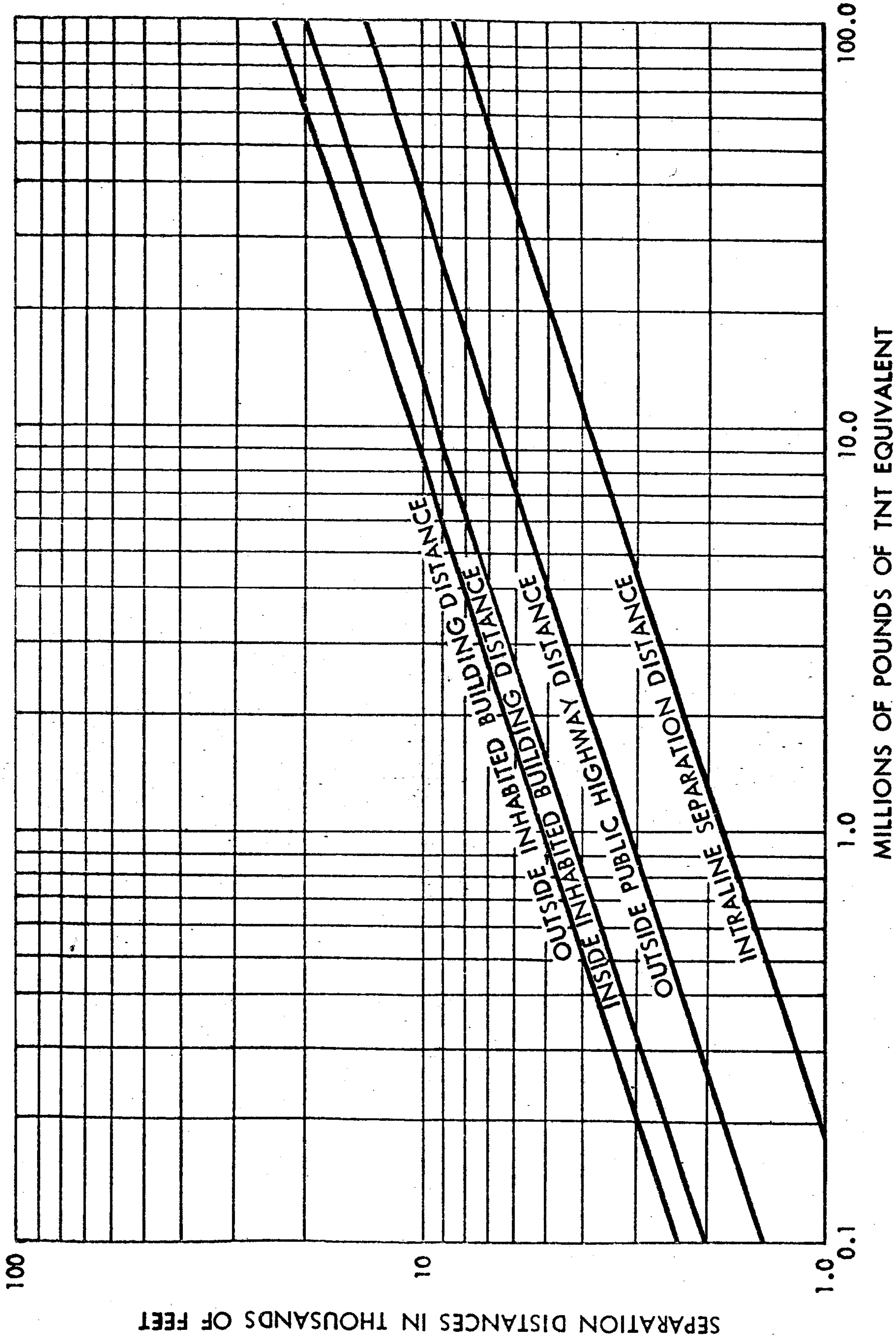


Fig. VI-10 QUANTITY-DISTANCE STANDARDS FOR CLASS 9 EXPLOSIVES

G. TRANSPORTATION AND HANDLING

Results of the Phase-I transportation study indicate that movement of solid booster motors and liquid stages could be accomplished by several different methods. The most suitable method for transporting a particular stage or component depends on its dimensions and weight. To a lesser degree, evaluation of the transport mode must consider such factors as quality of ride, safety, speed, and cost.

Operational concepts established for this study required handling and transportation of first step solid motors, both segmented and unitized designs, liquid upper stages and the completely assembled vehicle. The overall transportation and handling sequence applicable to the five airborne vehicle designs of this study is illustrated in Figure VI-11.

Where remote facility locations and details of cargo handling equipment are unknown, several assumptions must be made. Accordingly, the following items define the assumptions associated with this study.

1) The method of long-distance transportation of solid motor segments will be governed by route analysis between Utah and AMR. (When program launch rates require segment production capacity in excess of that available, then new facilities probably will be situated close to the launch site.)
2) Transportation of components and stages from remote facilities assumes that they have suitable loading equipment.
3) Transportation of components or stages by water (limited only to water transportation because of their physical characteristics) assumes that remote source facilities have access to a navigable waterway.
4) Unitized motors will be cast and cured in the vicinity of the launch site; empty cases will be transported from remote facilities.
5) Since details concerning the payload are unavailable, considerations for payload handling and transportation equipment will be omitted from this study.

(See Appendix 2, Section A-VI-D for detailed study of these areas.)

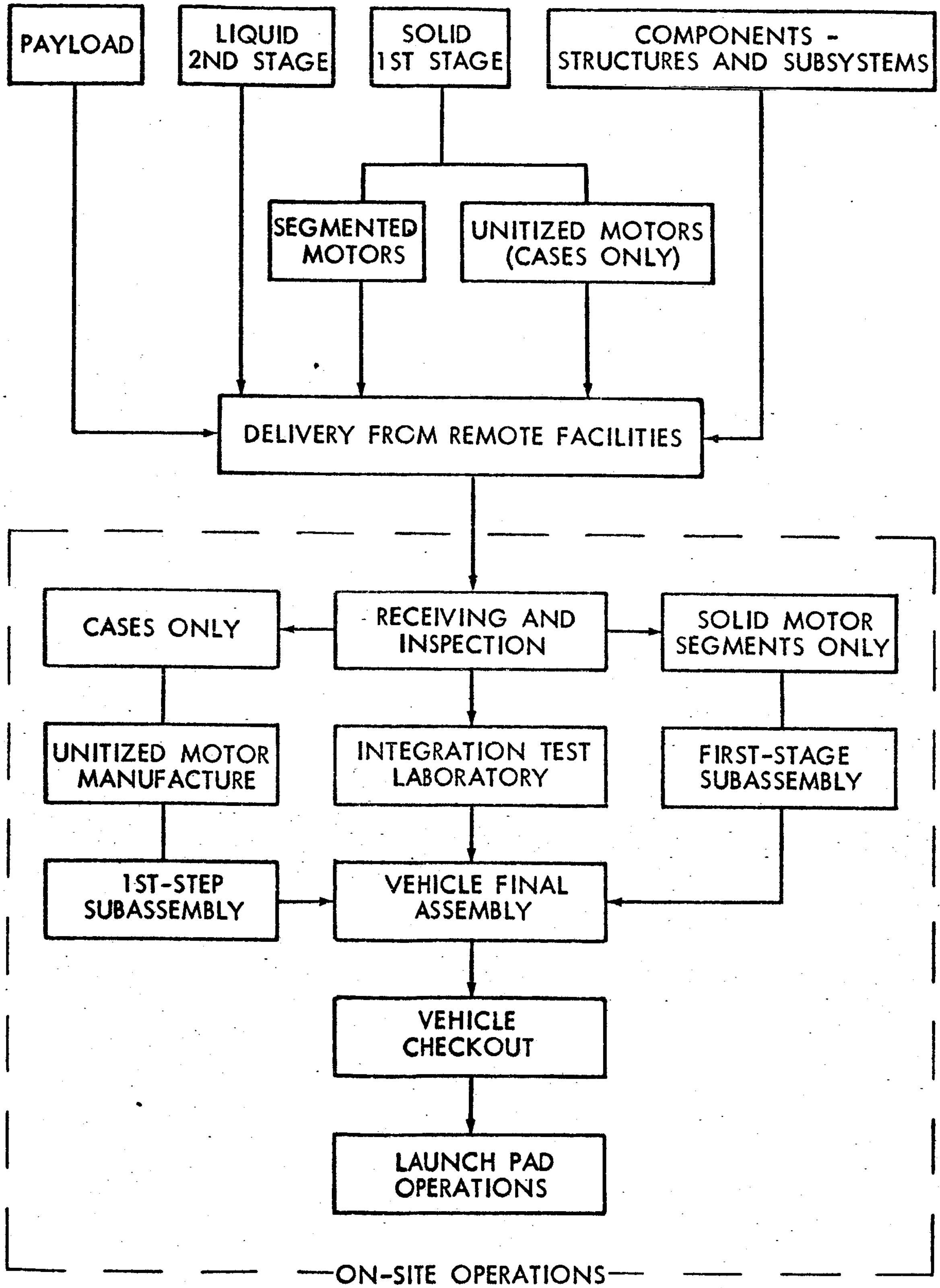


Fig. VI-11 TRANSPORTATION SEQUENCE

H. SCHEDULES

Construction schedules, which apply to the N-UC4 vehicle, are shown in Figures VI-12 through -17 for the propellant manufacturing vehicle assembly, and launch facilities and the ground support equipment. These schedules represent the worst condition as far as availability time is concerned since the facilities and equipment required to accomplish the Nova program will be the largest of all five vehicles considered. The availability dates shown for the various items are the earliest possible that they could be completed, so that the effects of possible schedule sliding can readily be seen.

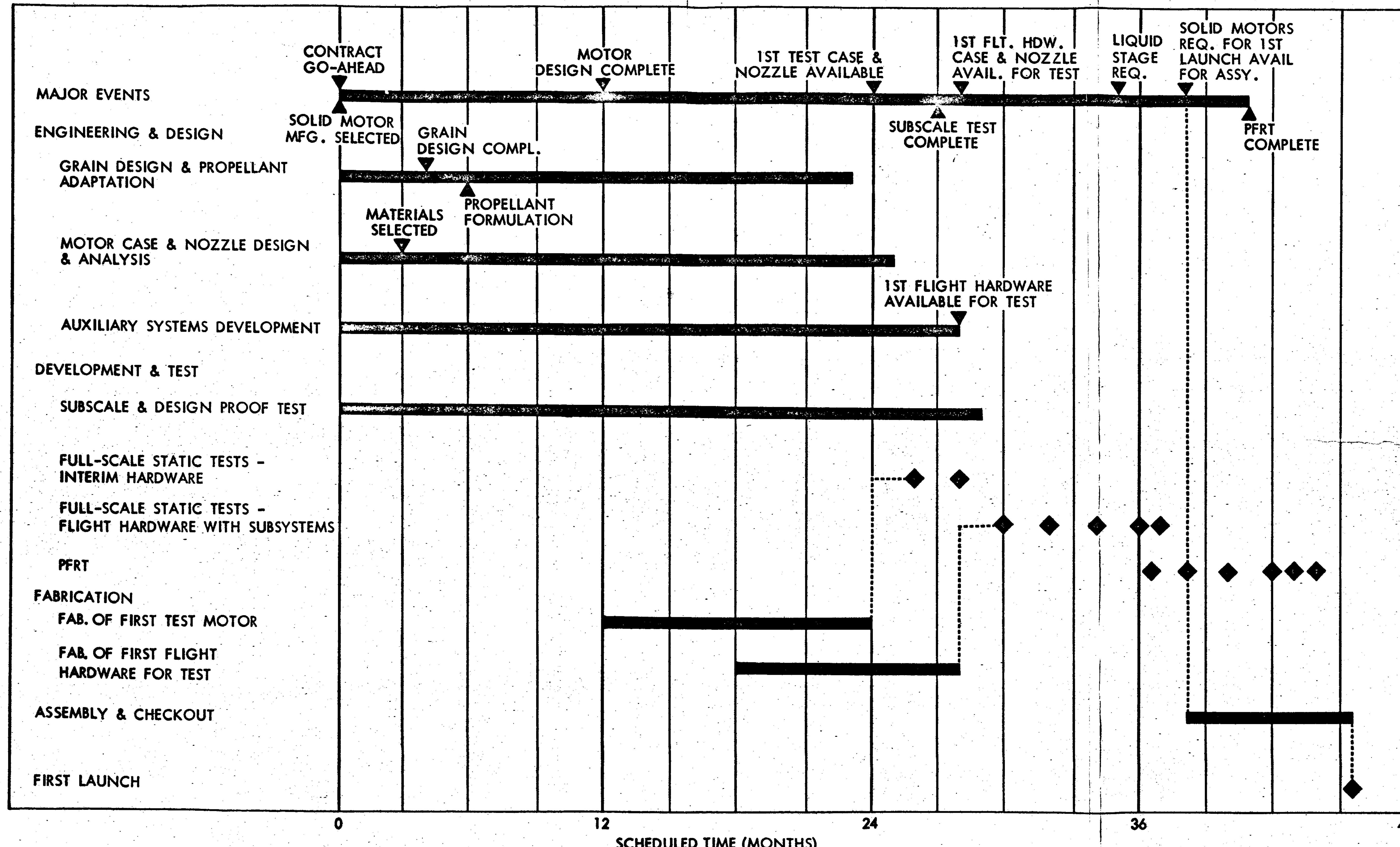


Fig. VI-12 PROPULSION SCHEDULE

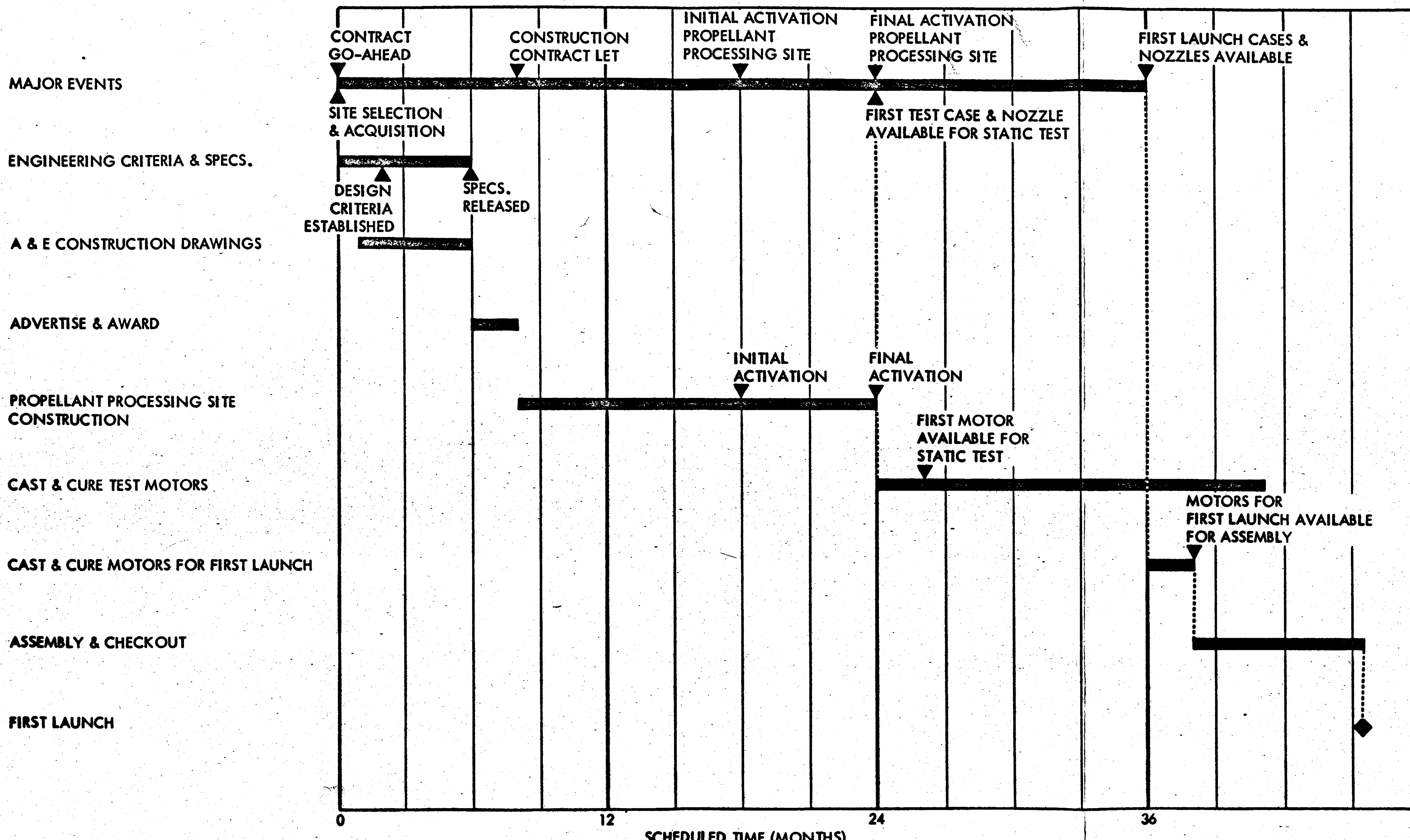


Fig. VI-13 PROPULSION FACILITY SCHEDULE

N-UC4

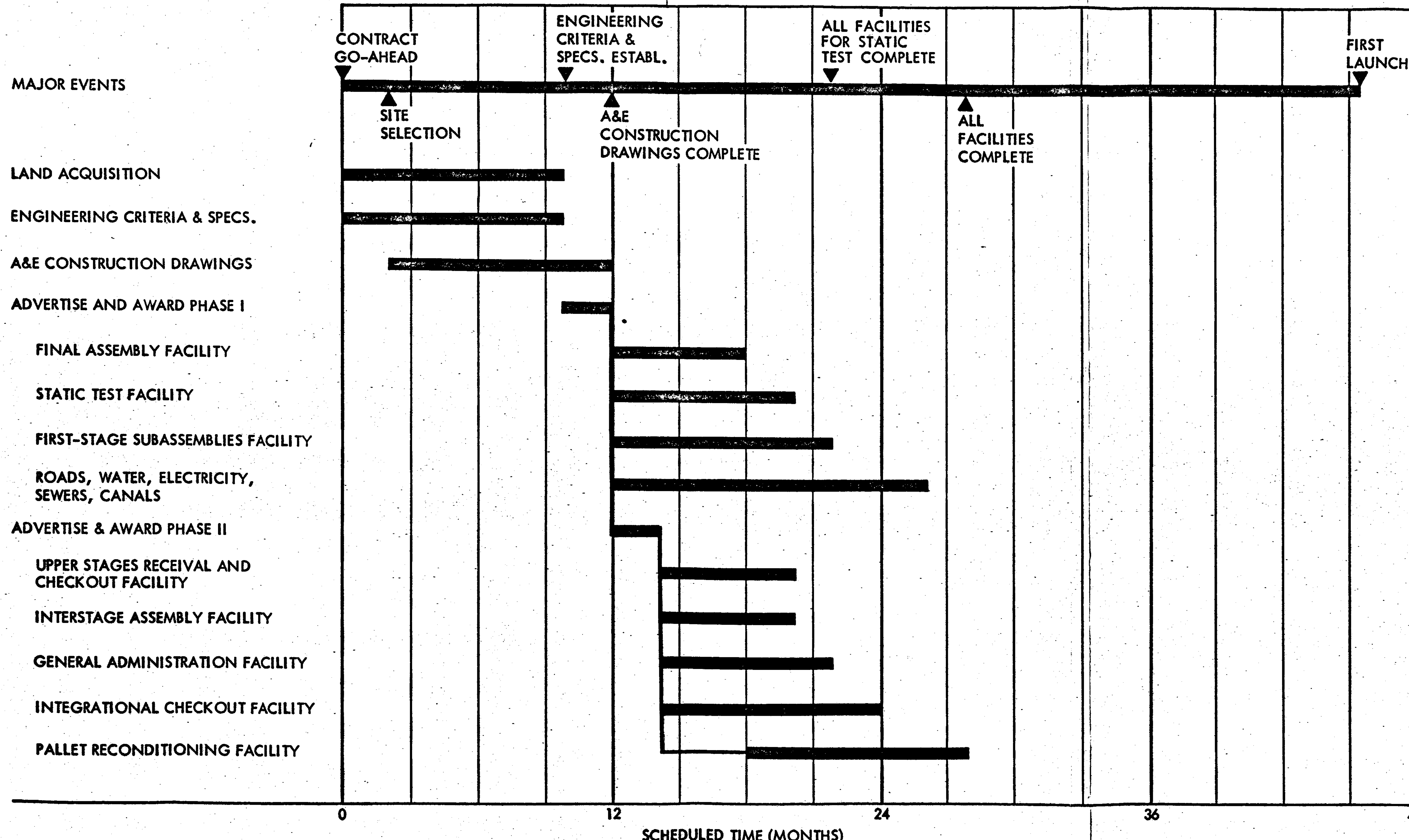


Fig. VI-14 ASSEMBLY COMPLEX FACILITY SCHEDULE

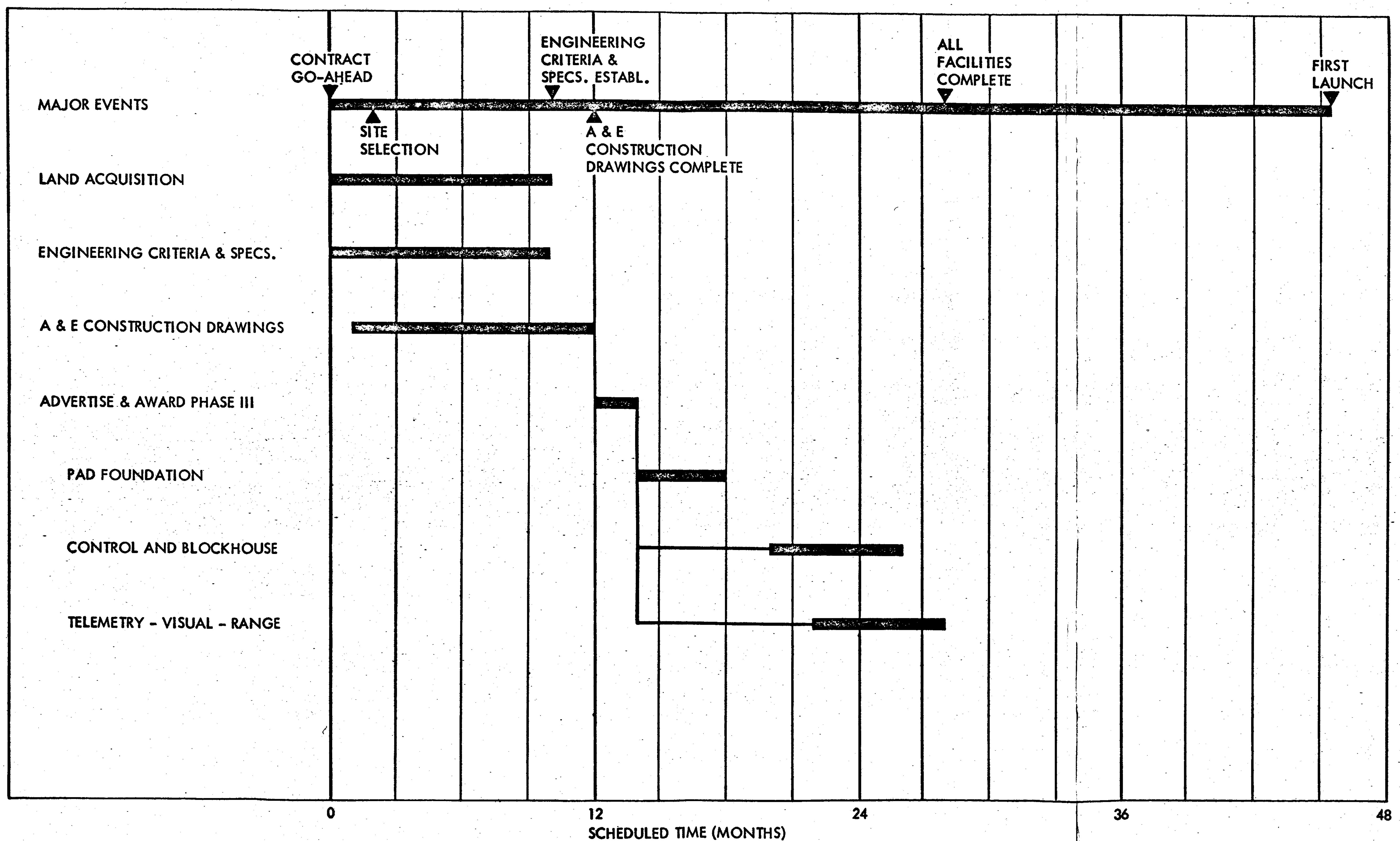


Fig. VI-15 LAUNCH COMPLEX FACILITY SCHEDULE

N-UC4

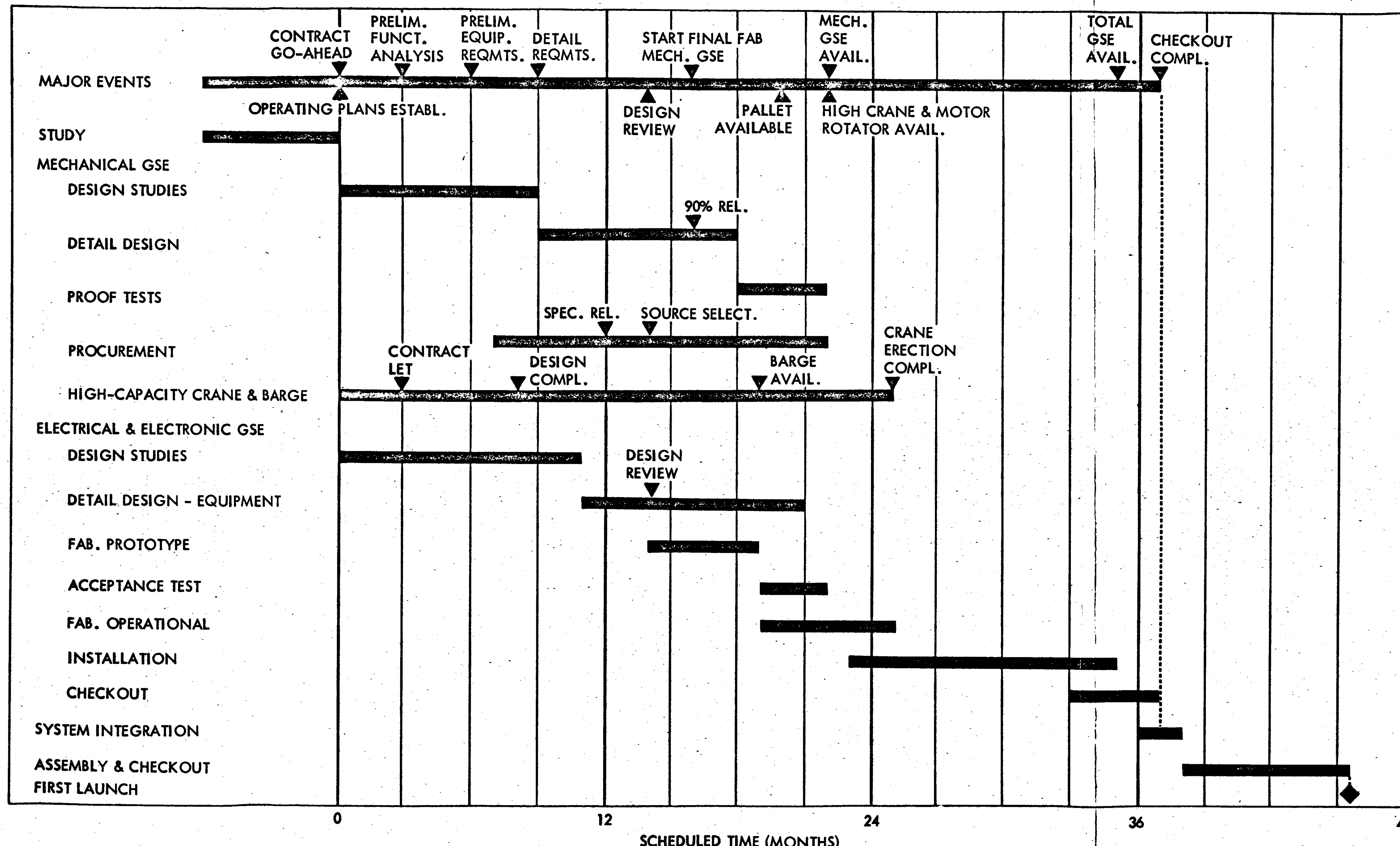


Fig. VI-16 GROUND SUPPORT EQUIPMENT SCHEDULE

N-UC4

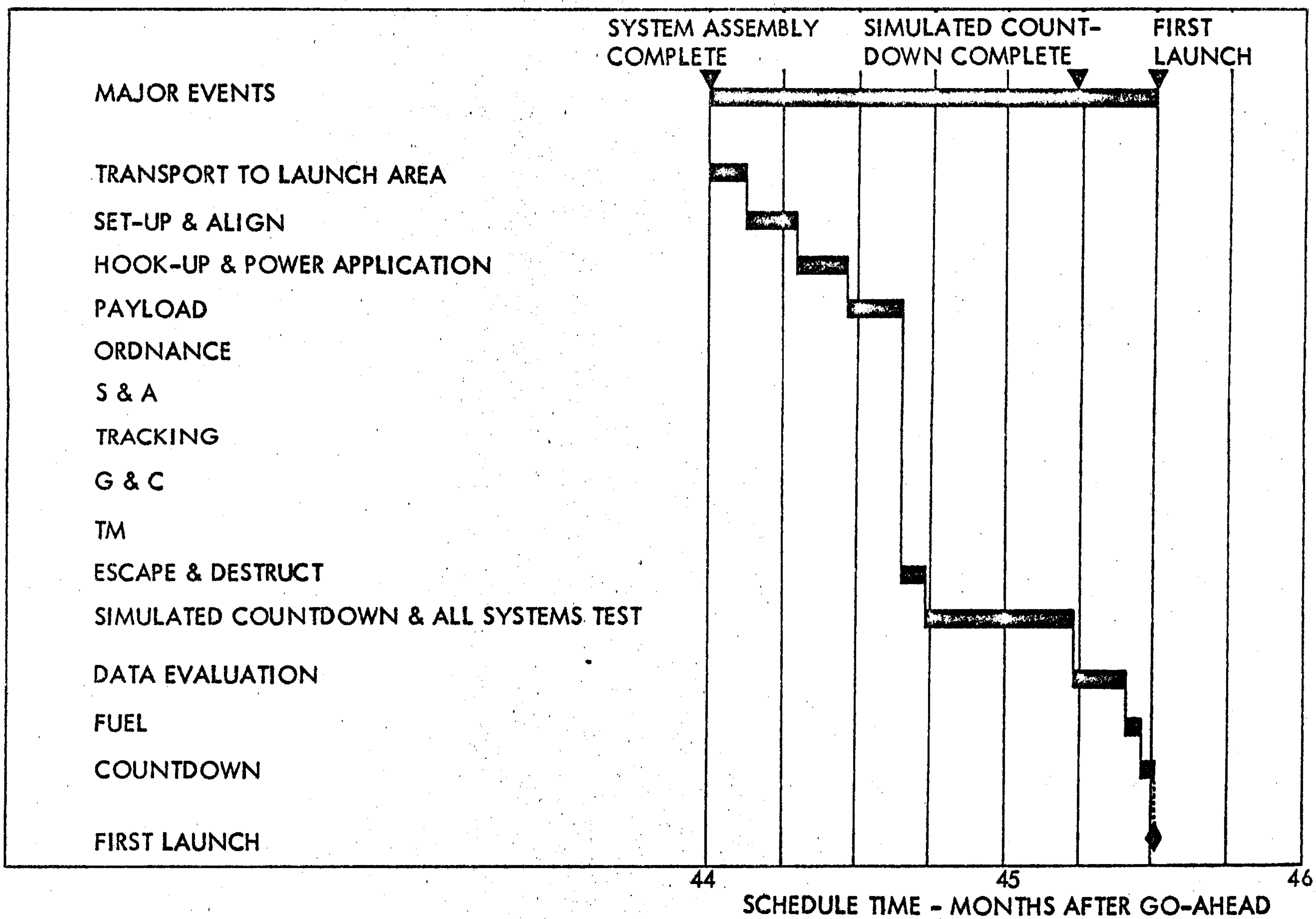


Fig. VI-17 LAUNCH AREA SCHEDULE

VII. MASTER SCHEDULES

A. PHASING SUMMARY

The phasing summary (Figure VII-1) represents a comparative analysis of each of the configurations. The intent is to show the variance of first launch and first manned launch, and the main events that have been considered in arriving at the times depicted. Phasing was developed by a careful, thorough evaluation of the tasks connected with the program. First, the critical and controlling elements of each task were identified; and then the time effort, and complexity interrelationships of these elements were assessed for optimum sequence of activities.

B. PROGRAMING APPROACH

It was assumed that a preliminary vehicle definition will be established by a special preliminary-design contractor, an in-house effort by the using agency, or by the initial effort of a system manager or prime contractor prior to R&D contract go-ahead. This will allow: motor-manufacturer selection at go-ahead and a motor design complete at 12 months; establishment of GSE operating plans consisting of general requirements and preliminary-design specifications; and early site selection and acquisition of new facilities, when required. Configuration phasing was developed with these assumptions.

1. SEGMENTED BOOSTER CONFIGURATIONS

1-S1

Existing manufacturing and propellant-processing facilities will be used to develop the segmented motors, which in turn enables the static test and PFRT programs to begin at an earlier time than unitized. Because of the advancement in industry of segmented-motor development, it is felt that only a short period is required to redesign motors already being developed, thus making the segmented motors a noncritical item. However, the size and complexity of the overall vehicle and

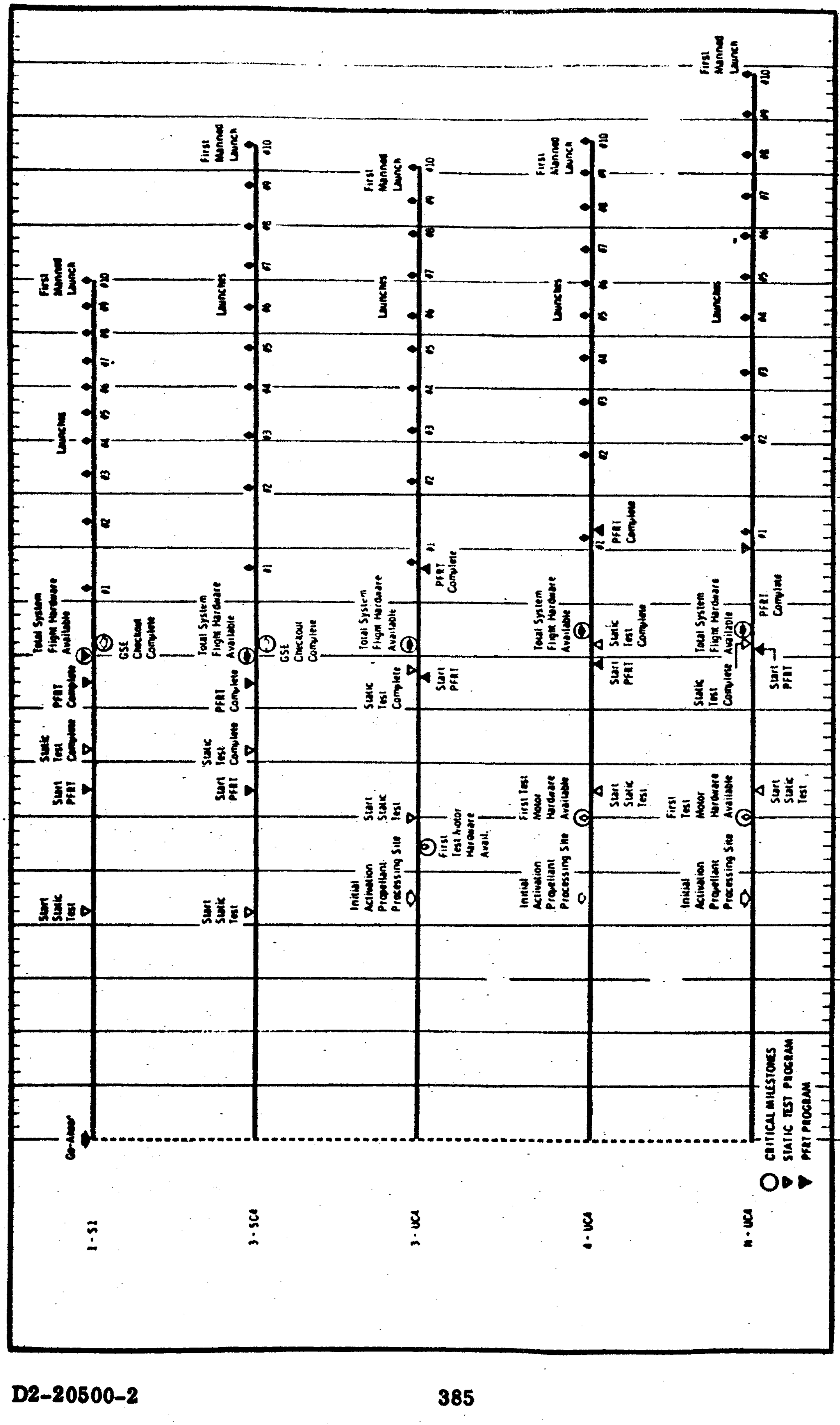


Fig. VII-1 PHASING SUMMARY

its launch complex have established the availability of the electric and electronic ground support equipment as a critical item.

3-SC4

The phasing for this configuration is the same as 1-S1 except that the availability of first flight airframe becomes a critical item along with the GSE due to a later final-drawing release date, which is predicated on the increase in size.

The first launch of the 1-S1 and 3-SC4 varies because of the longer period required for system integration and assembly and checkout of the larger configuration.

2. UNITIZED BOOSTER CONFIGURATIONS (3-UC4, 4-UC4, N-UC4)

Existing manufacturing facilities will be used but a new propellant-processing site is required. The propellant-processing site can be developed in 18 months after go-ahead and is not considered a critical item.

The unitized-motor development will start at go-ahead and will be a critical item on all unitized configurations as will the availability of first flight airframe hardware.

The launches vary due to the time required for integration, assembly, and checkout of the larger configuration.

C. PROGRAM PHASING

The following set of master program-phasing schedules (Figure VII-2 through VII-6) indicates the development time for the family of vehicles studied. Development prior to initial launch will require from 41 to 45.5 months. The schedules show the phasing of the major areas of work to accomplish this from an arbitrary time zero; however, a period for vehicle design and ground support equipment is required before go-ahead.

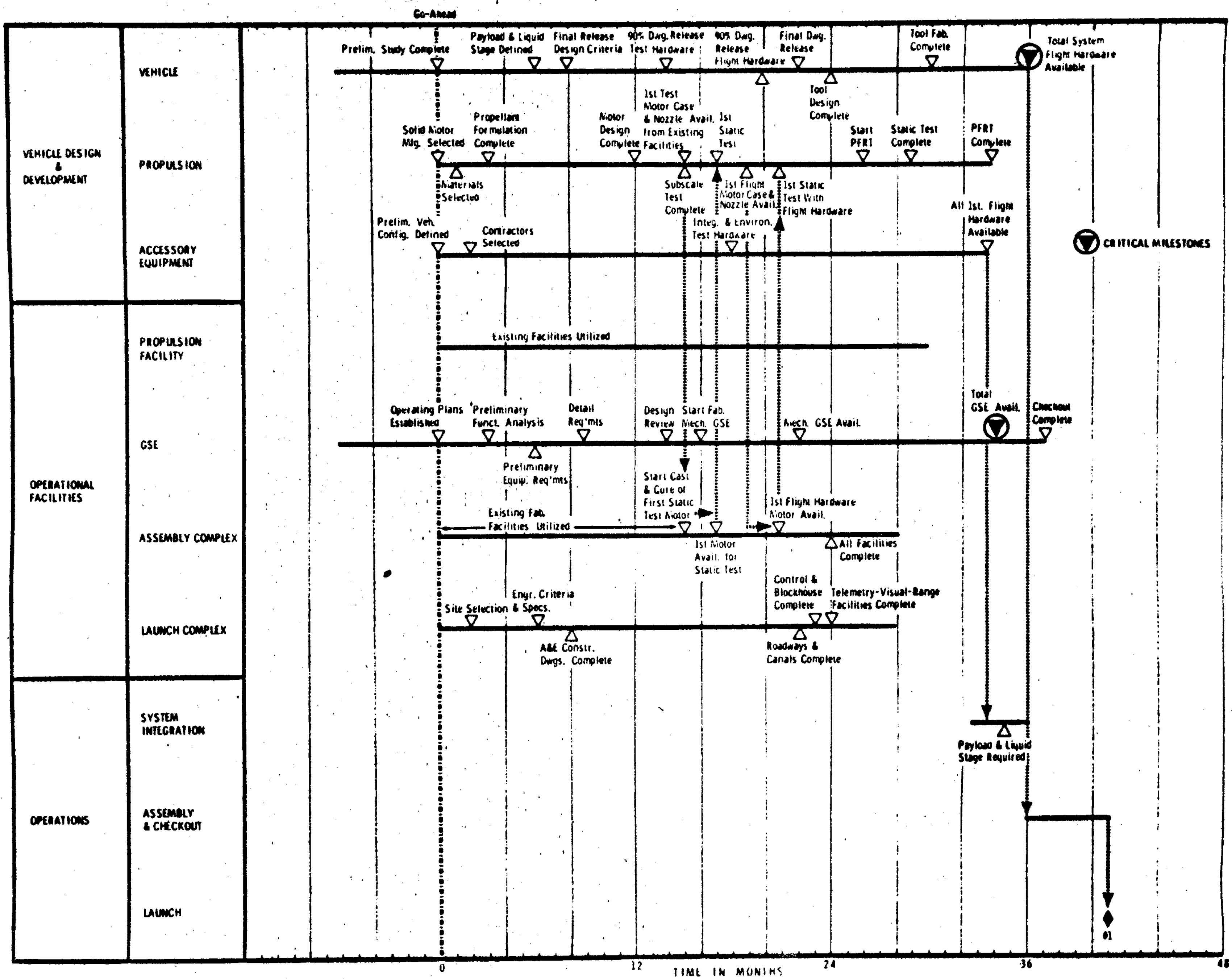


Fig. VII-2 PROGRAM PHASING – VEHICLE CONFIGURATION 1-S1

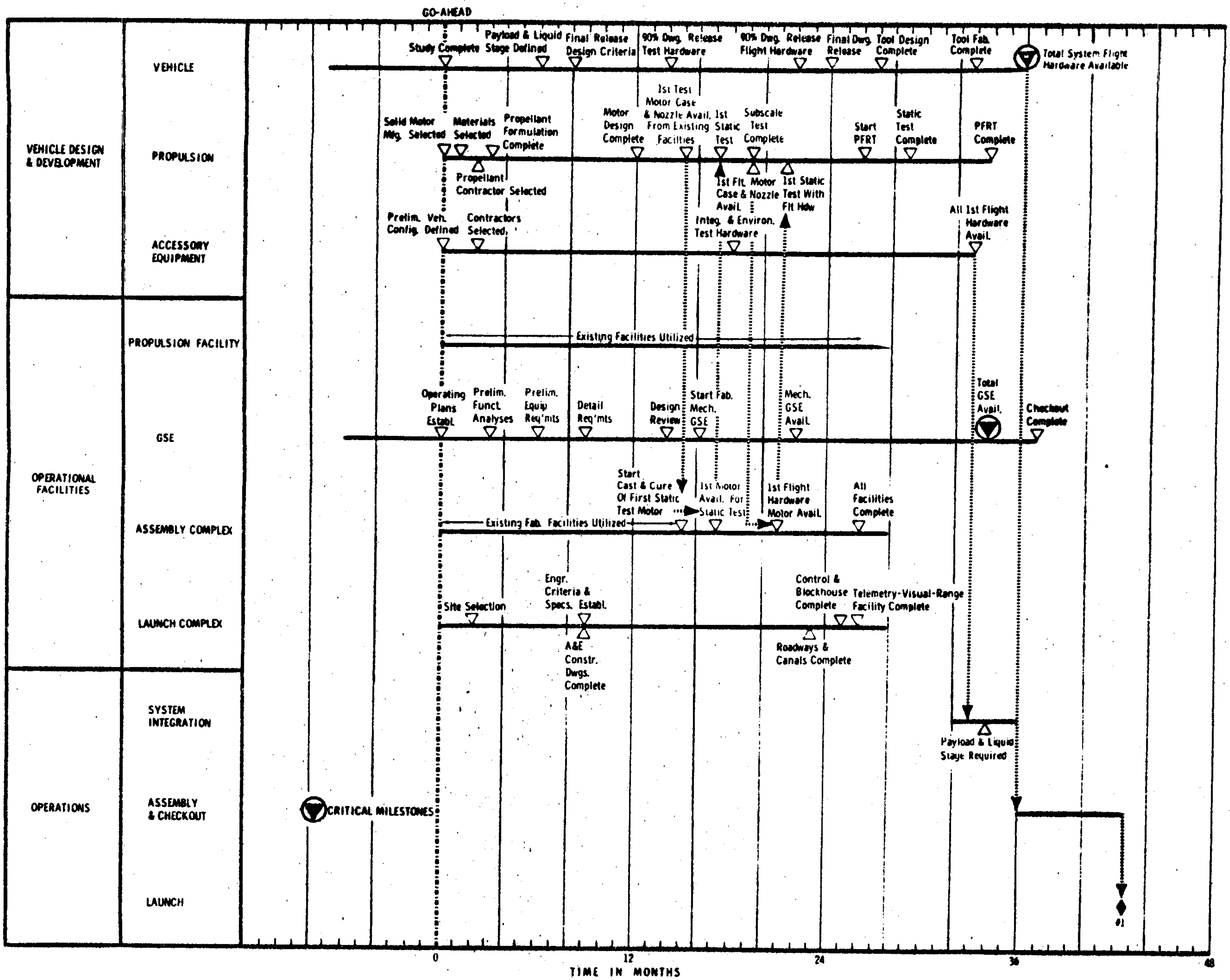


Fig. VII-3 PROGRAM PHASING - CONFIGURATION 3SC4

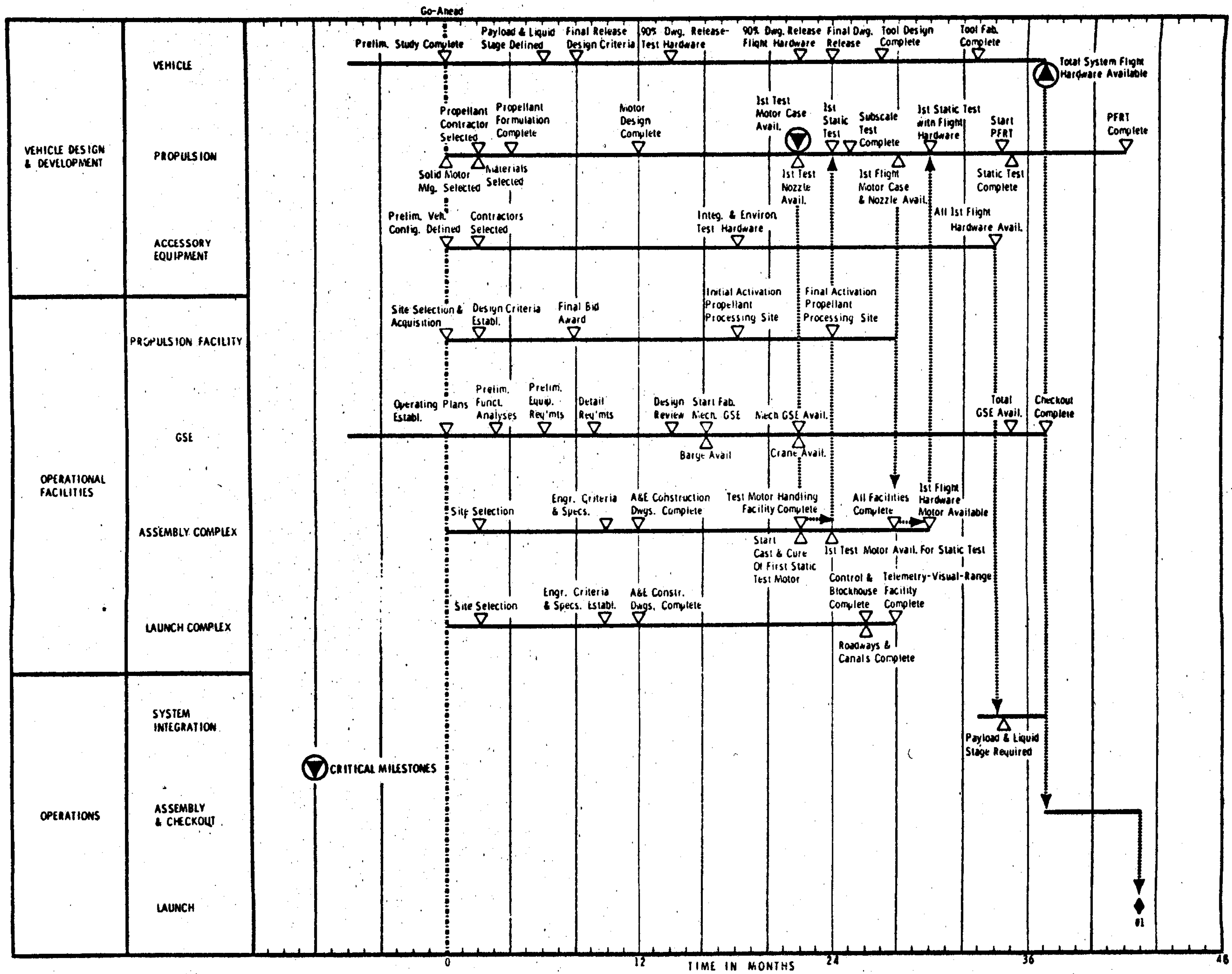


Fig. VII-4 PROGRAM PHASING – CONFIGURATION 3-UC 4

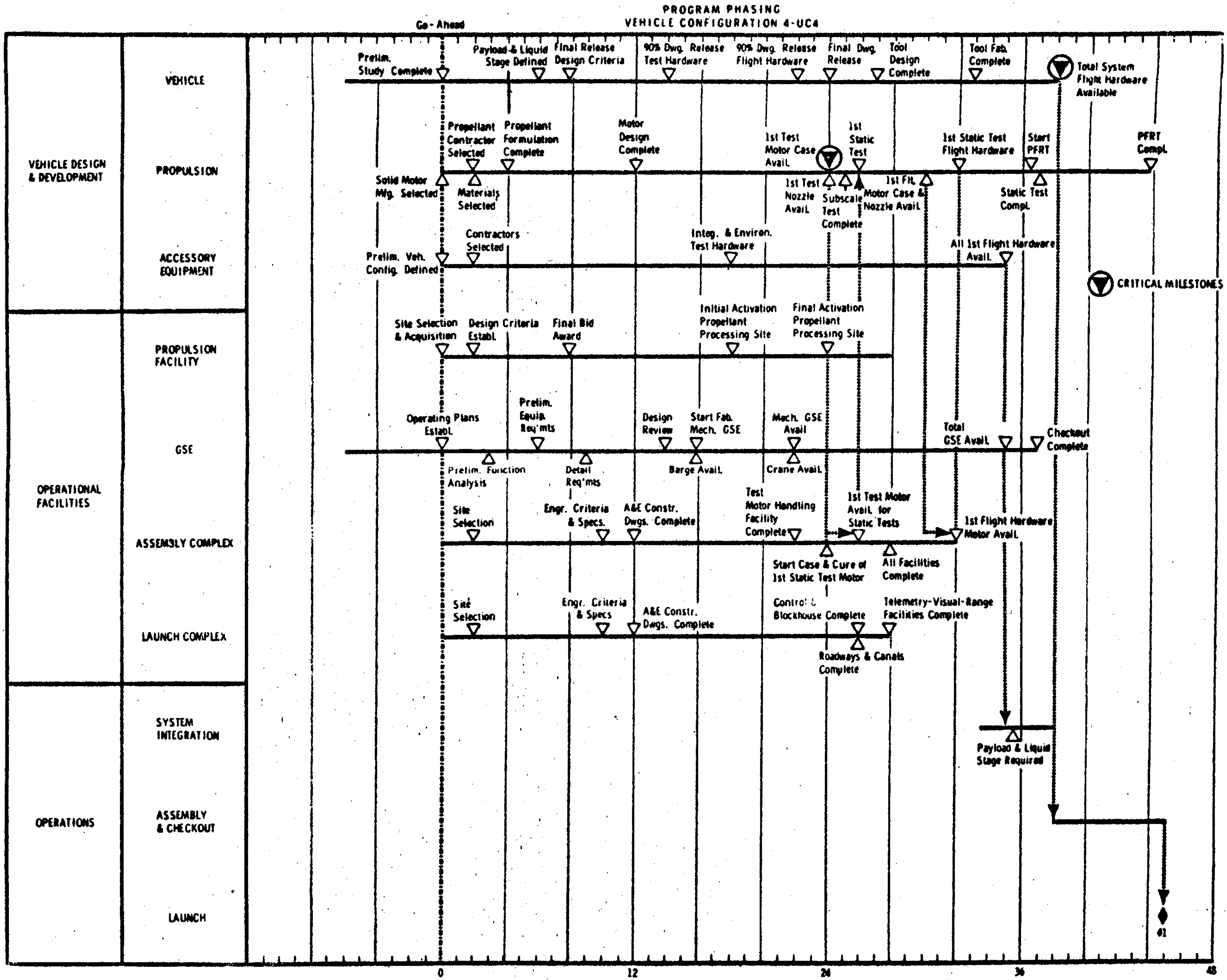


Fig. VII-5 PROGRAM PHASING – VEHICLE CONFIGURATION 4-UC4

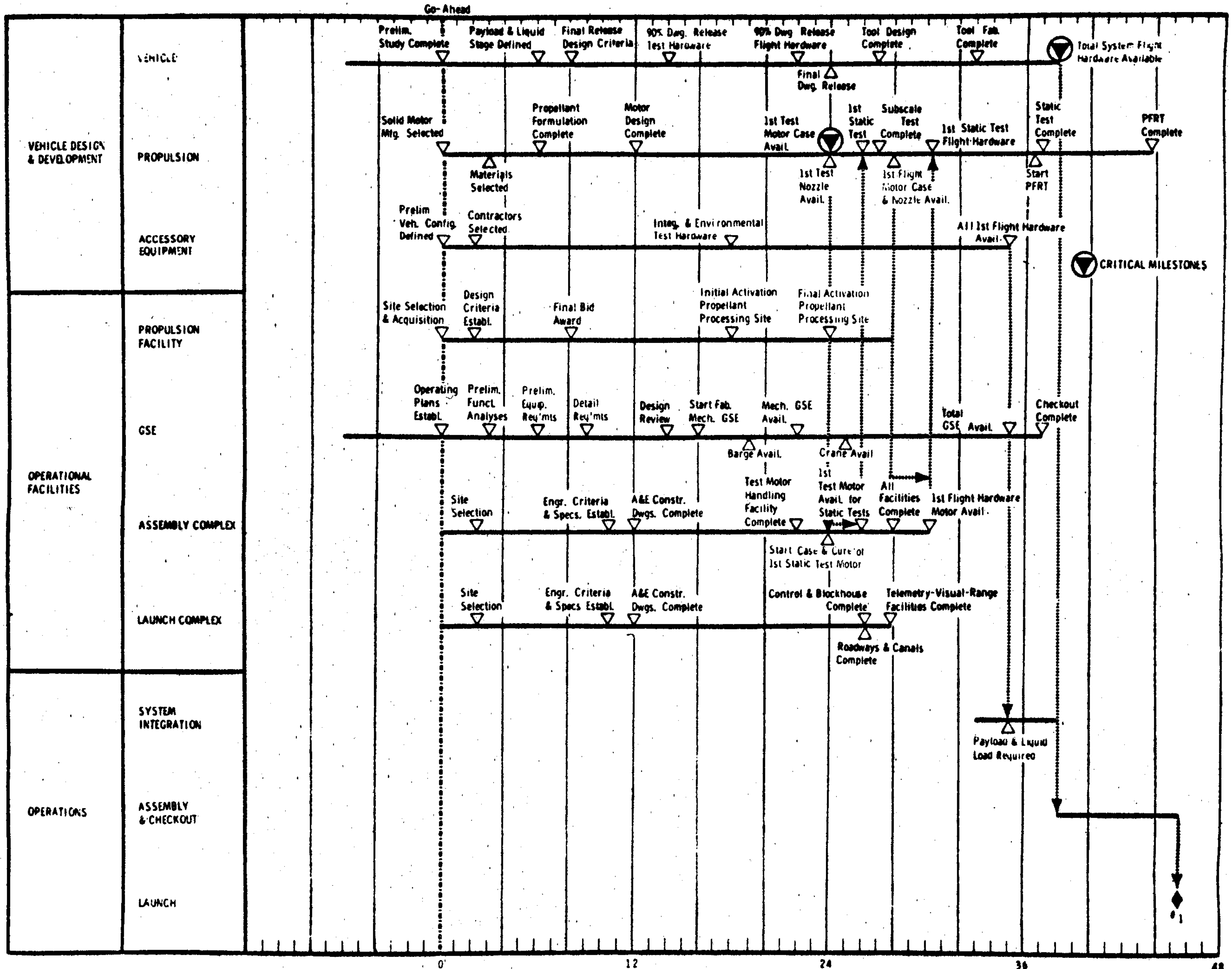


Fig. VII-6 PROGRAM PHASING – VEHICLE CONFIGURATION N-UC4

The schedules reflect what is required to accomplish the complete development of the vehicle; it is assumed that both the payload and the liquid stages will be available as required. No detail is shown for development of these items but their effect on system-integration testing, assembly, and prelaunch time requirements has been considered. Critical items for each program are emphasized by circling the normal milestones.

The master program-phasing schedule for vehicle configuration N-UC4 is backed-up with detail schedules in the various sections of this document. It was decided to use this configuration because it requires the longest development time to first manned launch.

The number of full-scale solid-motor tests for each configuration is as follows:

Configuration	Static Test with Interim Hardware	Static Test with Flight Hardware	PFRT
1-S1	2	7	7
3-SC4	2	7	7
3-UC4	3	4	7
4-UC4	3	4	7
N-UC4	2	5	6

VIII. QUALITY ASSURANCE PLAN

This section explains a plan to assure quality from vehicle design to delivery. In addition to complying with all the requirements for establishing and maintaining a quality control system consistent with acceptable specifications, this plan emphasizes the following:

A. COORDINATION

Coordination will be maintained with product engineering, manufacturing development, and quality control organizations to ensure that the development of adequate specifications, reliable inspection criteria, equipment, and techniques keep pace with engineering development in the design of aerospace vehicles.

B. INSPECTION AND TEST PROCEDURES

All functions or operations will be by fully documented and coordinated procedures that adequately define the inspection and/or test.

C. APPROVED SUPPLIERS

Material and process suppliers, including inspection processes, will be surveyed for capabilities prior to placement of contracts or purchase orders. Procurement will be limited to approved sources.

D. INSPECTION AT THE SOURCE

All inspections and/or tests will be at or as near the originating source as is possible or practical. Quality control surveillance of procurement sources will be maintained as required.

E. RECEIVING INSPECTION

Receiving inspection will include inspections and/or tests, as necessary, to confirm and ensure the integrity of purchased materials, equipment, and services.

F. IN-PROCESS INSPECTIONS

As much as possible, in-process control inspections will be automated and performed simultaneously with fabrication.

Problem areas or areas where applications of new techniques and improvements in existing techniques can be anticipated are discussed below.

1. CASE FABRICATION

WELDS

X-ray inspection will be used to check case welds, supplemented as necessary with magnetic methods. Fixed X-ray techniques, including the use of a tube with a 360-degree beam radius for girth welds, are adequate for this work. A flow time of about one hour per 90 feet of weld will be required. In-motion X-ray techniques have been studied with a view to reducing flow times, but they were found to be impractical for thick steel casings because of necessary case metal heat conditioning required immediately after welding. Ultrasonic techniques were also considered for weld evaluation. The method looks promising, but the present state of the art is not adequate to ensure proper inspection.

ALIGNMENT

Telescopes and a Universal Planizer will be used for alignment to eliminate the necessity for leveling the subassembly or finished case. Direct readings can be taken and the end faces oriented with the missile axis and with each other. The transit and level method is not feasible for this type of work, because it requires a state of levelness or complex calculations establishing a reference plane of levelness.

During assembly, when the telescope and universal planizer system is used to set up each completed case in relation to the other cases in the cluster, it will not be necessary to establish levelness. With this system, it is possible to match faces and assemble with a minimum of stress to the interface.

2. LINER AND INSULATION MANUFACTURE

Chemical tests are required for manufacturing control to verify the composition of materials used for insulation and liners after mixing. It will be necessary to develop such tests for many of the materials that may be used. In all cases, the weigh-up of raw materials will be verified for each batch and physical and visual tests made. Adhesion and thermal conductivity tests will be necessary to ensure that the final product meets specifications.

3. PROPELLANT MANUFACTURE

Propellant properties are critical and need tight in-process controls. The most effective in-process control is verification of the propellant mix composition. This may be a problem because it must be done before casting. The extent of the problem will depend on a number of factors including propellant formulation, test method development, and time interval between mixing and casting. A method for propellant formulations of two or three solids dispersed in a two polymer binder system may be realized with very little development of present technology. In more complex formulations, the analysis may be limited to measurement of three or four of the major constituents with the assumption that if they are correctly mixed other constituents are also. Such an assumption is generally correct, but there is room for doubt. From the standpoint of quality assurance, the use of the simpler propellants is recommended.

For large motors, mandatory techniques for composition analysis include the use of infrared absorption analysis for polymers and X-ray fluorescence for other materials. All tests must be completed and evaluated prior to casting. In addition, samples from each batch of propellant will be checked after curing to ensure that the final propellant will meet specifications.

G. FINAL INSPECTION

Final inspection of each solid propellant motor assembly will verify integrity of the subassemblies and systems and compatibility with intrastage components. Final inspection of the clustered stage will verify the integrity and compatibility of the components and intrastage systems with the interstaging and second stage/ payload. Checkout of the completed vehicle will establish intravehicle compatibility and integrity of all component systems and functions.

Problems anticipated at early stages of manufacture and assembly (under case fabrication for example), which will be compounded during the later stages of assembly, are illustrated below:

1. DIMENSIONAL ALIGNMENT

Optical systems will be used to control the profile of the assembled booster, subsequent stages, and the assembled launch vehicle. Two systems will be set up to check "banana effect" on two planes perpendicular to each other. This will be done with the universal planizer and telescope with no reference to levelness or plumb.

An optical system is currently under development (in final phase) to measure distortion of the shape of the case, stage, or assembled vehicle (if any) when the case, stage, or vehicle is positioned vertically on its launch pad. This is being developed as a result of problems encountered with the Minuteman and can be adapted to this program.

2. PROPELLANT INSPECTION

The major problem in assuring the quality of large solid propellant motors is examination of the propellant for discontinuities. There has been some conjecture in the industry that such examination is unnecessary since the effect of the anticipated voids and other defects would be of little consequence in a large mass of propellant. However, there is insufficient data available to support this contention, and the inspection of propellant is considered prudent, at least in the initial phases of production.

Radiographic inspection will be necessary for checking voids, cracks, and possible slump in the propellant. X-ray inspection of the motors will be made in the vertical position to avoid the handling and tooling required to move the motor to the horizontal. A 13 MEV radiographic linear accelerator is required, mounted so as to permit 360-degree movement of the machine around the motor. A distance of 30 feet from the X-ray target to the center of the motor must be maintained. The X-ray film, in a vacuum cassette, is positioned by means of a telescopic boom that moves up the center of the motors from the floor of the facility. Studies indicate that a 92- by 84-inch film array may be used with a 192-inch diameter motor.

A flow time of approximately 126 hours will be required with this facility for X-ray inspection, including placement and exposure of film. This X-ray inspection will show voids, cracks, and some serious separations at the forward end of the forward closure. However, there are definite limitations in this X-ray technique. It will not detect separations between the case and liner or liner and propellant in most of the forward closure, cylindrical body section, or aft closure. The X ray should be supplemented with the accepted ultrasonic inspection method to check case-to-liner separations.

In addition, a method for the visual examination of the motor internal configuration for cracks is suggested. This would consist of a camera mounted with the necessary lenses and lighting on the end of the X-ray film positioning boom to photograph the interior surfaces of the propellant.

The most difficult problem is the detection of separations between liner and propellant. This is considered to be a risky condition, particularly in the aft closure. Further development is needed for instrumentation and procedures to detect this type of anomaly. Ultrasound and infrared techniques are being investigated currently, but neither can be applied reliably at this time.

The infrared technique is based on the measurement of the thermal gradient that exists on the case surface of a solid propellant rocket motor as a result of discontinuities below the surface. Some development of the infrared technique is in progress for other programs, particularly Polaris, and it is anticipated that a practical system for smaller motors will be available in about one year. However, additional research will be necessary to adapt the system for large motors. For example, to use the infrared method, a temperature difference must be established between the propellant and the case surface. This is relatively simple with a smaller motor that may be handled in a temperature controlled environment. For large motors, it may be feasible to establish temperature differences in local areas or conduct the infrared test near the end of the propellant cure cycle but before the propellant attains ambient temperature. In addition, scanning and readout systems must be developed and evaluated.

It is estimated that the development of an infrared detection system for checking grain-liner separations will require about 18 months and cost approximately $250,000.

IX. RELIABILITY AND CREW SAFETY

A. RELIABILITY

1. SUMMARY AND CONCLUSIONS

Reliability analyses were made for 6 study configurations. These analyses include estimates of initial reliability as well as predictions of reliability growth. The configurations analyzed were two-stage boosters with solid-motor first stages and LO_2/LH_2 propellant second stages. The vehicles varied in payload capacity from 30,000 pounds to 350,000 pounds. The booster characteristics which caused reliability differences between configurations were the type of motor (solid or liquid), the number of propulsion units in each stage, and the method of staging (tandem or lateral).

Historical missile and space booster data for static and flight test were used as a basis for the reliability predictions for the booster configurations. However, only a limited amount of reliability information is available on either solid boosters over 100,000 pounds of thrust or LO_2/LH_2 propellant boosters of any size. Qualitative evaluation of subsystems,failure-mode analyses, projection of trends and manufacturers test data, and analytical data inputs were used to predict reliabilities for the large boosters.

Estimates of the initial flight reliabilities were made for each booster. The values are for a reliability range which may be expected, depending on the extent of the development effort. The median value of reliability for the single engine (1-S1) booster was estimated to be .706. For the large tandem-staged vehicles, the median reliability value was .436.

Engine redundancy in the second stage will raise the values for the multiengine configurations. For the tandem staged vehicle the median value becomes .658 instead of .436, assuming 10 percent of engine failures uncontrollable.

The estimated reliabilities are achievable only after extensive design efforts and test programs. It is not economically feasible to demonstrate the desired level of reliabilility in the test program.

CONCLUSIONS

1) Booster size should be determined from considerations other than reliability. The quantity of propulsion units is significant. The quantity of motors should be kept low for solid stages for highest reliability.
2) Engine redundancy was required in the clustered engine second stages of the study configurations. This redundancy will be required until such time that the engines have demonstrated much higher reliabilities than the median values predicted in this study.

2. INTRODUCTION

Six booster systems were analyzed to determine their reliability characteristics. The characteristics determined were reliability at first launch, reliability growth, initial operating reliability, and point reliabilities for each launch. Cumulative growth curves are necessary for economic analysis. Point reliability is of value in selecting the safe point for the first manned launch. Initial operating reliability is a measure of the test effort required.

Figure IX-1 is a sketch of the 6 boosters. The principal items which cause the differences between the booster reliabilities are shown. Five of the boosters have two stages with conventional tandem staging. The other booster is laterally staged. First stage propulsion consists of solid motors in all configurations using currently developed propellants.

The engines in the second stages use a LO_2/LH_2 propellant. The engines are of the J-2 type, except for the largest NOVA booster. The NOVA has 3 Y-1 engines in the second stage.

Flight control is provided by liquid-injection thrust-vector control on the solid motors.

NOTED DESIGNATION OF VEHICLE

S SEGMENTED MOTOR
U UNITIZED MOTOR
C CLUSTERED MOTOR
L LATERAL STAGE

THE SECOND NUMERAL STANDS FOR THE NUMBER OF ENGINES IN THE FIRST STAGE.

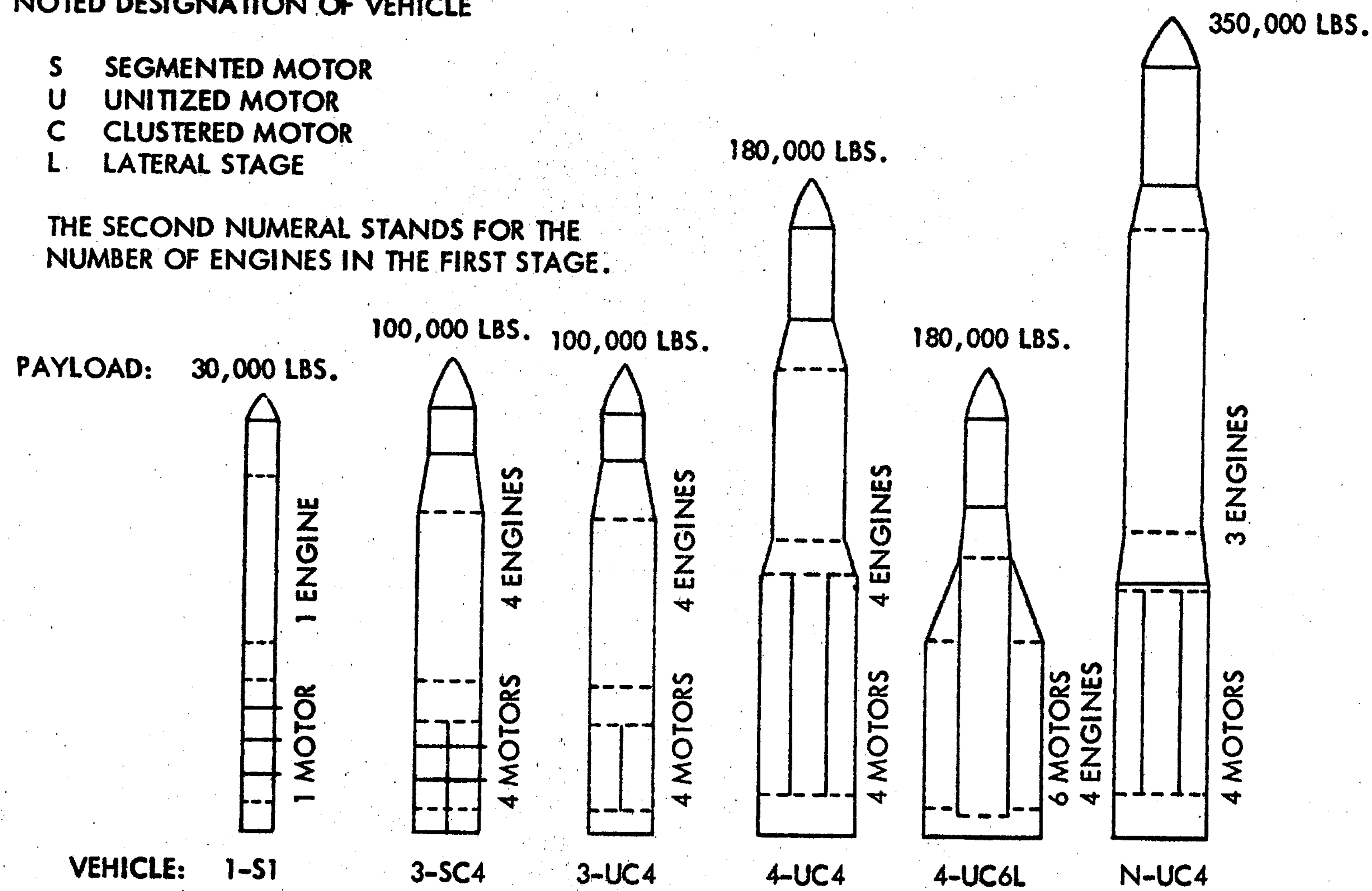


Fig. IX-1 BOOSTER CONFIGURATIONS

Flight control of the second stages is provided by gimbaling the liquid engine nozzles. Fins are used where required for each booster to meet the minimum prescribed level of stability. The equipment for guidance and control and stability augmentation is similar for all configurations.

Separation of the first and second stages is effected by using 4 solid retrorockets. An unpowered and uncontrolled period occurs after first-stage burnout. Four fuel-ullage rockets provide low thrust immediately preceding second-stage ignition.

Separation problems are common for the five tandem-staged boosters. The reliability of the subsystem providing separation is assumed to be the same in each case. However, the laterally staged vehicle required a more complex separation subsystem than those boosters with tandem stages.

Trajectories are similar for each booster. The equipment environment is assumed to be the same in each vehicle (i.e., acceleration, temperature, pressures, sonic level, etc., are of the same magnitude).

3. RELIABILITY ANALYSIS

Four major reliability areas were investigated: (1) determination of the effect of motor design on motor reliability, (2) comparison of segmented and unitized motor design reliabilities, (3) estimation of subsystem reliabilities, and 4) prediction of reliability growth. Background data and the method of analysis are in Sections IXA5 and IXA6.

EFFECT OF MOTOR DESIGN

The motor designs for both the solid and liquid propellant propulsion units vary with respect to size and/or burning time. Historical flight data was used as a basis for evaluating the effect of these variations.

An analysis of historical flight data (see Appendix I) on solid-propellant propulsion units considered motors containing 31 pounds of propellant to motors containing over 43,000 pounds of propellant—an increase of approximately 1400 to 1. The historical data did not indicate any relationship of size to reliability within this weight range. The weight increase from the 43,000-pound motor to the motors considered in this study is less than 45 to 1. For this study, it was assumed that size alone does not influence reliability.

The historical flight data covered burning times ranging from 2.1 seconds to 58.6 seconds. This represents an increase in burning time of approximately 28 to 1. No relationship between burning time and reliability existed in this data. Burning times for the motors used in this study are less than 2 times the longest burning time in the data analyzed. For this study, it was assumed that the burning time of the solid motors does not change the reliability.

An analysis of historical flight data on liquid-propellant propulsion units (see Appendix I) resulted in the conclusion that the size and/or burning time of the engine does not affect the reliability of the unit as long as the systems are of comparable complexity.

COMPARISON OF SEGMENTED AND UNITIZED MOTOR DESIGNS

Historical test data was analyzed to obtain the failure modes observed on unitized solid-motor propulsion systems. Discussions concerning static tests of the large unitized and segmented motors were held with the manufacturers. Their analytical data on these large boosters was reviewed. This data was not adequate for a quantitative evaluation of the two types of solid motors. A qualitative comparison of the probability of failure occurrence of a segmented design is given in terms of lower, same, or higher (Table IX-1).

Table IX-1

SEGMENTED VERSUS UNITIZED MOTOR DESIGNS

Observed Modes of Failure of Unitized Designs	Probability of Failure Occurrence for Segmented Designs
Nozzle failures	same
Chamber rupture	lower
Aft closure burn-through	lower
Chamber burn-through	same
Forward-head rupture	lower
Ignition adapter failure	same
Ignition	same
Insulation	higher
Propellant to liner bond	lower
Propellant void	lower
Weld cracks	same
Strap joint leak	same
Throat and exit liners	same
Closure "O" ring	same
Thrust vector control	same
Grain restriction	higher
Excessive chamber pressure	same
Heating at aft closure	same
Loss of pressure	higher

The segmented design contains segment joints which are subject to failure, whereas the unitized motor has an integral propellant grain. The limited number of tests conducted to date with segmented motor designs does not permit a quantitative evaluation of reliability. Based on the preceding qualitative discussion, it was concluded that the reliability of the segmented design would be equivalent to that demonstrated for a unitized design.

RELIABILITY ESTIMATES

Reliability estimates were computed for the first launch of each of the 6 study configurations. These estimates were based on the historical flight data contained in the appendix document. Reliability estimates for space boosters differ from estimates for missile boosters because of design differences (i.e., higher structural safety factors, malfunction detection systems, etc.).

Three reliability estimates (low, medium, high) were obtained for each configuration. These estimates correspond to three levels of development: (1) the low estimate corresponds to a limited development effort where development time may be more important than reliability; (2) the medium estimate corresponds to a normal development effort where reliability, cost, and development time are given equivalent emphasis; and (3) the high estimate corresponds to an intensive development effort where reliability is more important than cost or development time. For purposes of test programing and scheduling, the median value was used throughout.

Reliability estimates for the C-1 class vehicle are shown in Table IX-2. This vehicle has one solid motor in the first stage and one LO_2/LH_2 J-2 type engine in the second stage.

Table IX-2

RELIABILITY ESTIMATES FOR CONFIGURATION*
1-S1

Stage One	Low	Medium	High
Propulsion	0.950	0.990	0.995
Thrust vector control	0.950	0.970	0.990
Stage Guidance and Controls	0.980	0.990	0.995
Structure/separation	0.990	0.995	0.999
Ignition	1.000	1.000	1.000
Instrumentation	0.990	0.995	1.000
Retrorocket (4)	0.961	0.980	0.996
Human factor	0.990	0.999	1.000
Stage Total	0.824	0.921	0.975

* These values are lower than previously reported in D2-13029 due to the addition of retrorockets to the vehicles.

Table IX-2 (Cont.)

Stage Two	Low	Medium	High
Propulsion	0.855	0.930	0.980
Thrust vector control	0.906	0.950	0.990
Stage guidance and controls	0.950	0.977	0.990
Structure/separation	0.985	0.993	0.999
Ignition	0.980	0.990	0.999
Instrumentation	0.972	0.990	0.999
Propellant feed	0.950	0.975	0.995
Pressurization	0.980	0.990	0.999
Retrorocket (4)	0.961	0.980	0.996
Ullage motors (4)	0.961	0.980	0.996
Human factor	0.950	0.985	1.000
Stage Total	0.564	0.767	0.944
System Total	0.465	0.706	0.920

Table IX-3 gives reliability estimates for the C-3 and C-4 class tandem-staged vehicles. The number of propulsion units is the same in both stages; four solid motors in the first stage and four J-2 type LO_2/LH_2 engines in the second stage. The differences in the configurations are the motor type (segmented or unitized) and motor length. Since it was assumed in this study that motor type and size do not affect reliability, the three configurations were given the same reliability estimates.

Table IX-3

RELIABILITY ESTIMATES FOR STUDY CONFIGURATIONS*

3-SC4
3-UC4
4-UC4

Stage One	Low	Medium	High
Propulsion (4 motors)	0.814	0.961	0.980
Thrust vector control	0.885	0.913	0.975
Stage guidance and controls	0.980	0.990	0.995
Structure/separation	0.990	0.995	0.999
Ignition	1.000	1.000	1.000
Instrumentation	0.990	0.995	1.000
Retrorockets (4)	0.961	0.980	0.996
Human factor	0.990	0.999	1.000
Stage Total	0.658	0.854	0.945

Stage Two	Low		Medium		High	
Propulsion (4 J-2's)	0.548	0.800**	0.748	0.951**	0.922	0.991**
Thrust vector control	0.674	0.927**	0.814	0.968**	0.961	0.996**
Stage guidance and controls	0.925	0.925	0.952	0.952	0.980	0.980
Structure/separation	0.985	0.985	0.993	0.993	0.999	0.999
Ignition	0.980	0.980	0.990	0.990	0.999	0.999
Instrumentation	0.972	0.972	0.990	0.990	0.999	0.999
Propellant feed	0.938	0.938	0.970	0.970	0.990	0.990
Pressurization	0.971	0.971	0.985	0.985	0.990	0.990
Retrorockets (4)	0.961	0.961	0.980	0.980	0.995	0.995
Ullage motors (4)	0.961	0.961	0.980	0.980	0.995	0.995
Human factor	0.930	0.930	0.985	0.985	1.000	1.000
Stage Total	0.251	0.504	0.510	0.771	0.840	0.936
System Total	0.165	0.332	0.436	0.658	0.794	0.884

* These values are lower than previously reported in D2-13029 due to the addition of retrorockets to the vehicles

** Engine and thrust vector control-out capability (10 percent catastrophic failures).

The reliability estimates for the C-4 class laterally staged vehicle are contained in Table IX-4. This configuration is composed of six solid motors in the first stage and four J-2 LO_2/LH_2 engines in the second stage. The reliability estimate for structure and separation was assumed to be lower for this laterally staged vehicle than it was for the tandem-staged vehicles.

Table IX-4

RELIABILITY ESTIMATES FOR STUDY CONFIGURATION 4-UC6L

Stage One	Low	Medium	High
Propulsion (6 motors)	0.735	0.942	0.970
Thrust vector control	0.833	0.872	0.942
Stage guidance and controls	0.980	0.990	0.995
Structure/separation	0.970	0.980	0.990
Ignition	1.000	1.000	1.000
Instrumentation	0.990	0.999	1.000
Retrorockets (4)	0.961	0.980	0.995
Human factor	0.990	0.999	1.000
Stage Total	0.548	0.784	0.895

Stage Two	Low		Medium		High	
Propulsion (4 J 2's)	0.548	0.800**	0.748	0.951**	0.922	0.991**
Thrust vector control	0.674	0.927**	0.814	0.968**	0.961	0.996**
Stage guidance and controls	0.925	0.925	0.952	0.952	0.980	0.980
Structure separation	0.985	0.985	0.993	0.993	0.999	0.999
Ignition	0.980	0.980	0.999	0.990	0.999	0.999
Instrumentation	0.972	0.972	0.990	0.990	0.999	0.999
Propellant feed	0.938	0.938	0.970	0.970	0.990	0.990
Pressurization	0.971	0.971	0.985	0.985	0.990	0.990
Retrorockets (4)	0.961	0.961	0.980	0.980	0.995	0.995
Ullage motors (4)	0.961	0.961	0.980	0.980	0.995	0.995
Human factor	0.930	0.930	0.985	0.985	1.000	1.000
Stage Total	0.251	0.504	0.510	0.771	0.840	0.936
System Total	0.138	0.276	0.400	0.604	0.752	0.838

* These values are lower than previously reported in D2-13029 due to the addition of retrorockets to the vehicles.

** Engine and thrust vector control-out capability (10% catastrophic failures).

The reliability estimates for the NOVA class vehicle are contained in Table IX 5. This configuration has four solid motors in the first stage and three Y-1 (1,000,000 pound thrust) type LO_2/LH_2 engines in the second stage. The Y-1 engine was assumed to have the same reliability during the first flight as the J-2 engine.

Table IX-5

RELIABILITY ESTIMATES FOR CONFIGURATION N-UC4*

Stage One	Low	Medium	High
Propulsion (4 motors)	0.814	0.961	0.980
Thrust vector control	0.885	0.913	0.975
Stage guidance and controls	0.980	0.990	0.995
Structure/separation	0.990	0.995	0.999
Ignition	1.000	1.000	1.000
Instrumentation	0.990	0.995	1.000
Retrorockets (4)	0.961	0.980	0.995
Human factor	0.990	0.999	1.000
Stage Total	0.658	0.854	0.945

Stage Two	Low		Medium		High	
Propulsion (3 Y-1's)	0.625	0.750**	0.804	0.915**	0.941	0.970**
Thrust vector control	0.744	0.820**	0.857	0.905**	0.970	0.980**
Stage guidance and controls	0.925	0.925	0.952	0.952	0.980	0.980
Structure/separation	0.985	0.985	0.993	0.993	0.990	0.990
Ignition	0.980	0.980	0.990	0.990	0.999	0.999
Instrumentation	0.972	0.972	0.990	0.990	0.999	0.999
Propellant feed	0.938	0.938	0.970	0.970	0.990	0.990
Pressurization	0.971	0.971	0.985	0.985	0.990	0.990
Human factor	0.930	0.930	0.985	0.985	1.000	1.000
Retrorockets (4)	0.961	0.961	0.980	0.980	0.995	0.995
Ullage motors (4)	0.961	0.961	0.980	0.980	0.995	0.995
Stage Total	0.316	0.418	0.577	0.693	0.857	0.892
System Total	0.208	0.275	0.493	0.592	0.810	0.843

* These values are lower than previously reported in D2-13029 due to the addition of retrorockets to the vehicles.

** Redundant valves, servos, etc. in propulsion and thrust vector control systems.

PREDICTED RELIABILITY GROWTH

Reliability growth curves were predicted for each of the study configurations. The predicted curves were obtained by using the following 4-step process.

1) The reliability prediction equation (Equation 1), Section IXA6, was used to obtain the predictions.
2) Values were obtained for the equation parameters from the reliability estimates contained in Section IXA3.
3) The point reliability growth (probability of successful launch) was predicted for each configuration.
4) The cumulative reliability curve (percent successful launches) was obtained by integrating the point reliability curve.

The most obvious problem revealed by the reliability estimates is that the boost reliabilities are probably unacceptably low, except the high subsystem estimates.

The differences between the redundant and nonredundant liquid versions are most dramatic at the medium and high estimates. Design for engine-out capability, where applicable, seems clearly indicated by this result.

The major sources of unreliability are in the propulsion subsystem, as might have been anticipated from experience with other systems.

The median reliability estimates were used as a basis for predicting the reliability growth of the study configurations. It is felt that the medium estimates can be achieved within the predicted development schedule for each configuration. The reliability at any point in the launch schedule is significantly higher than those demonstrated by present systems. The slope of the redundant curve is less than that of the nonredundant curve. This is a result of the difficulty involved in improving components that are already highly reliable.

Figure IX-2 shows the point reliability and the percent of successful launches as a function of the total number of launches for Configuration 1-S1. Figure IX-3

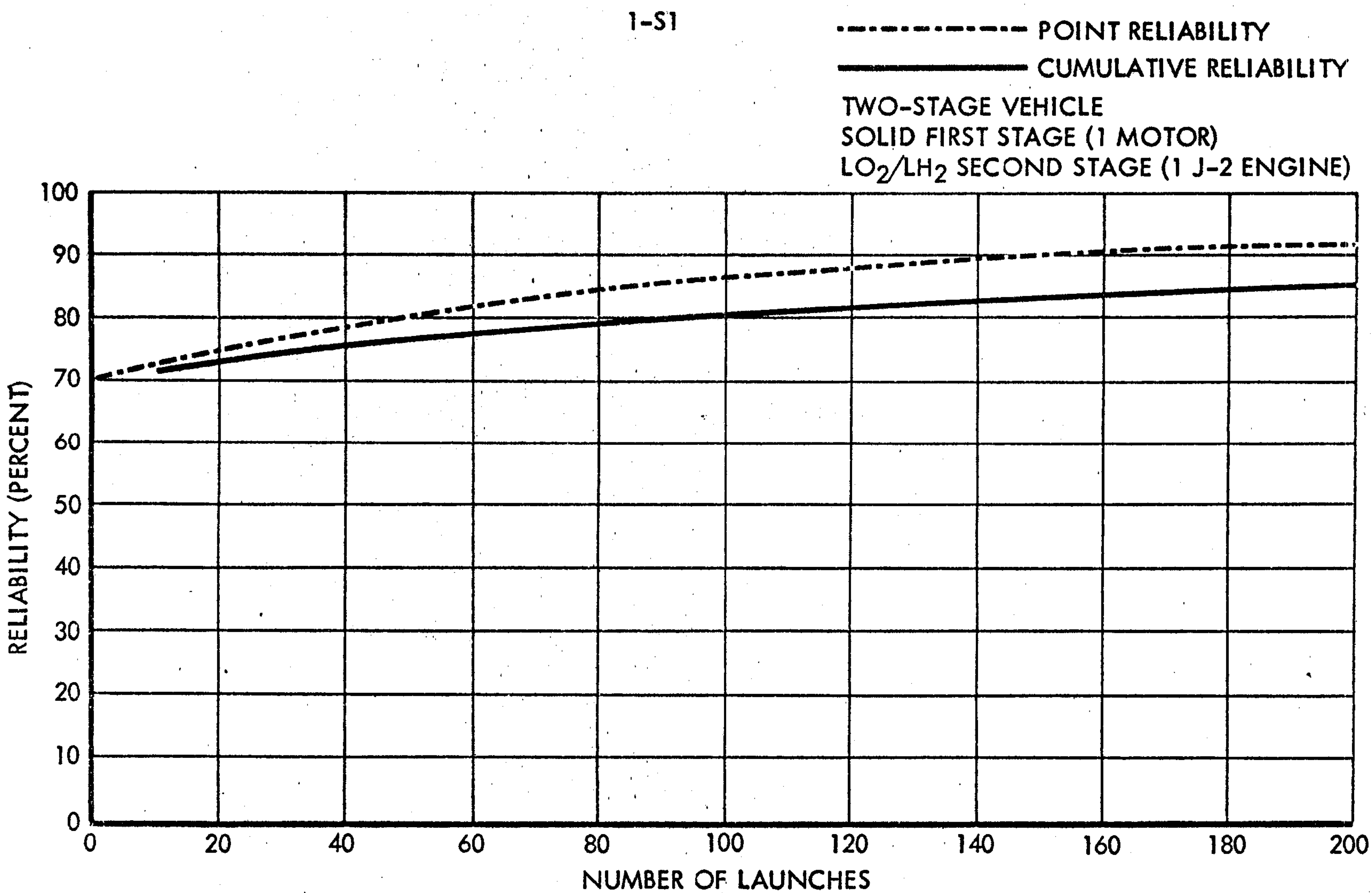


Fig. IX-2 CUMULATIVE RELIABILITY GROWTH CURVE

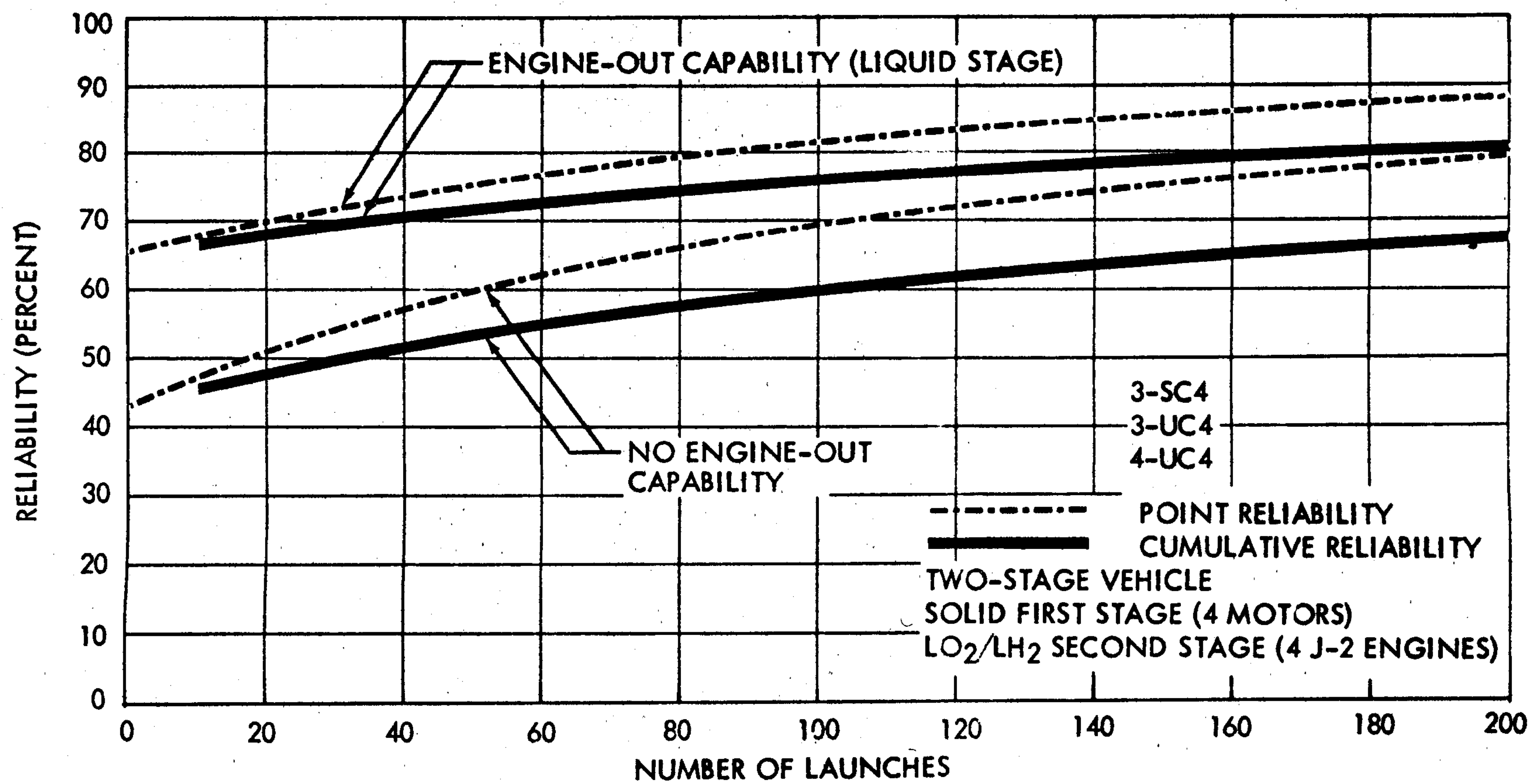


Fig. IX-3 CUMULATIVE RELIABILITY GROWTH CURVE

shows the point reliability and the percent of successful launches for Configurations 3-SC4, 3-UC4, and 4-UC4. These three vehicles have the same predicted growth because the number of propulsion units in each system is the same. Two curves are shown for both the point and cumulative reliability growth of these vehicles (i.e., the curve with no engine-out capability and the curve with engine-out capability). Figure IX-4 shows the point reliability and the percent of successful launches for Configuration 4-UC6L. No engine-out capability and engine-out capability curves are shown. Figure IX-5 shows the point reliability and the percent of successful launches for the N-UC4 configuration. The curves with no redundancy in the propulsion unit or thrust-vector control system and the curves with redundant values, servoactuators, etc., are shown.

It is apparent from Figures IX-3, IX-4, and IX-5 that engine-out capability (redundancy) considerably improves the reliability of the vehicles.

The percent of successful launches for each of the study configurations and the NASA launch schedules is shown in Table IX-6. These percents of successful launches were used as one parameter in the systems evaluation.

4. RELIABILITY TEST AND ASSURANCE PROGRAM

The achievement of reliability goals requires a reliability program that ensures a continuous and intelligent effort in the design and test program. One approach toward a successful program is outlined below.

Reliability analyses will be performed to establish reliability goals and to assist in achieving these goals. The major reliability considerations follow.

1) Goals will be established for the most economical level of vehicle reliability consistent with requirements for crew safety, range safety, and mission accomplishment.
2) The system will be defined by operating conditions and its sequence of functions.
3) Failure data will be collected and analysed to assist in assigning failure rates to the parts, components, subsystems, and total system of the vehicle.

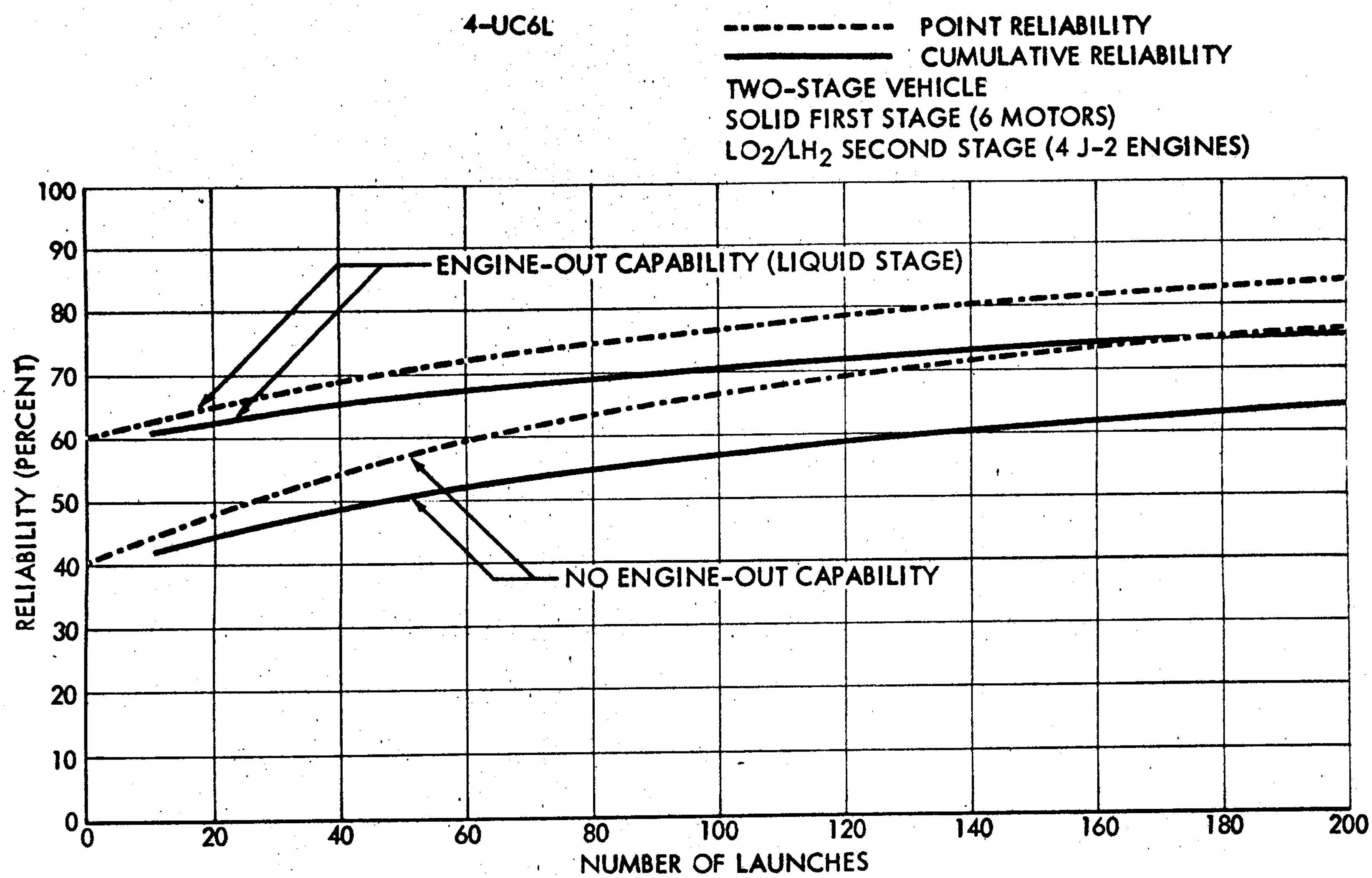


Fig. IX-4 CUMULATIVE RELIABILITY GROWTH CURVE

N-UC4

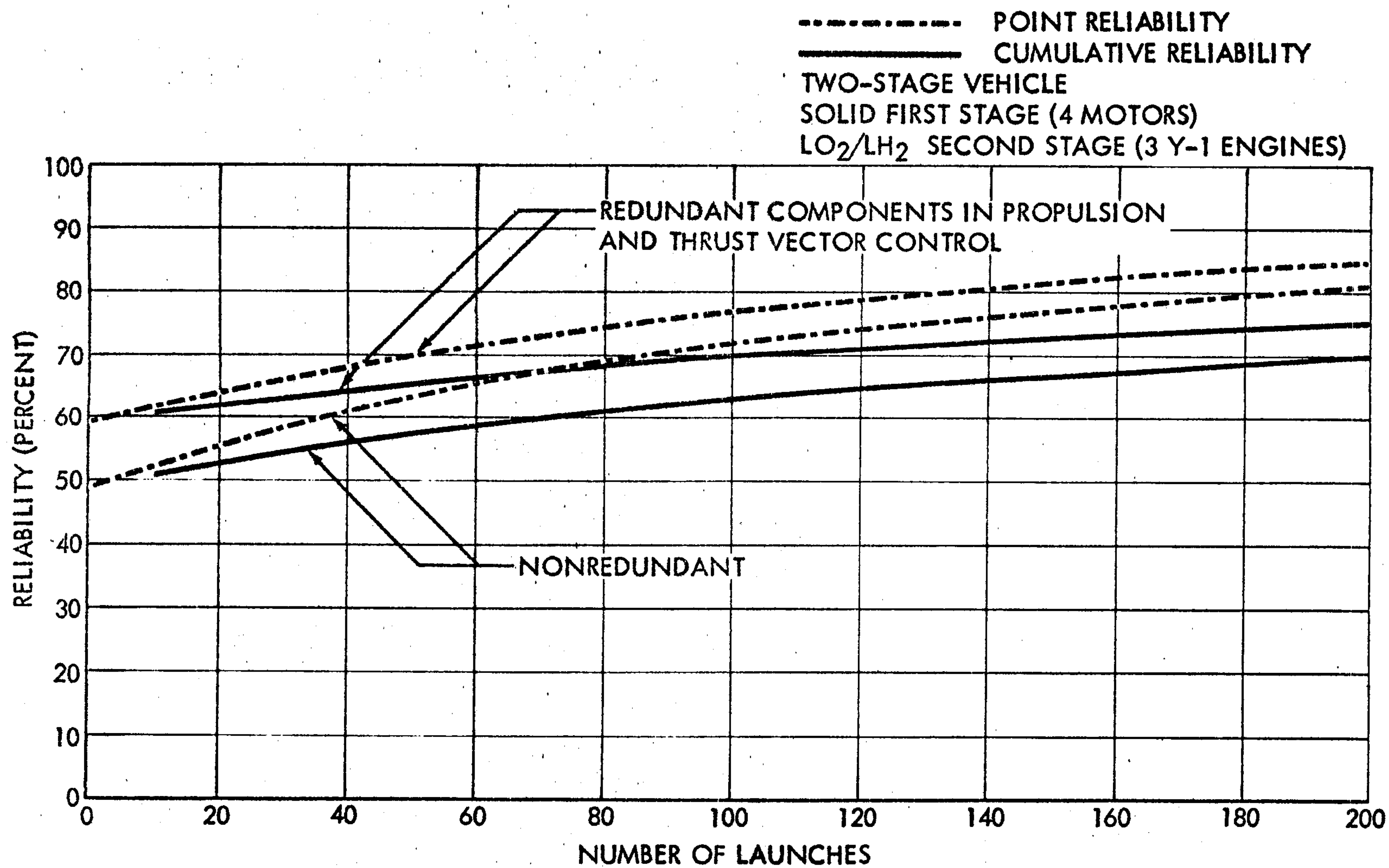


Fig. IX-5 CUMULATIVE RELIABILITY GROWTH CURVE

Table IX-6

PERCENT SUCCESSFUL LAUNCHES*
(Nonredundant upper stages)

Configuration	LAUNCH SCHEDULE ENCLOSURE 1** NUMBER OF LAUNCHES 111	330	666
	Percent Successful		
1-S1	81.0	87.9	91.3
3-SC4	61.0	72.9	79.0
3-UC4	61.0	72.9	79.0
4-UC4	61.0	72.9	79.0
4-UC6L	58.0	69.5	75.1
N-UC4	64.0	75.1	80.9

Configuration	LAUNCH SCHEDULE ENCLOSURE 2** NUMBER OF LAUNCHES 54	184	332
	Percent Successful		
1-S1	76.5	84.3	87.9
3-SC4	54.0	66.7	72.9
3-UC4	54.0	66.7	72.9
4-UC4	54.0	66.7	72.9
4-UC6L	51.0	63.0	69.5
N-UC4	58.0	69.0	75.1

PERCENT SUCCESSFUL LAUNCHES
(Redundant upper stages)

Configuration	LAUNCH SCHEDULE ENCLOSURE 1** NUMBER OF LAUNCHES 111	330	666
	Percent Successful		
3-SC4	77.0	84.2	88.5
3-UC4	77.0	84.2	88.5
4-UC4	77.0	84.2	88.5
4-UC6L	71.2	79.4	84.0
N-UC4	70.7	79.7	84.8

Configuration	LAUNCH SCHEDULE ENCLOSURE 2** NUMBER OF LAUNCHES 54	184	332
	Percent Successful		
3-SC4	72.0	80.0	84.2
3-UC4	72.0	80.0	84.2
4-UC4	72.0	80.0	84.2
4-UC6L	66.5	75.0	79.4
N-UC4	66.0	74.5	79.7

* These values are lower than those previously reported in D2-13029 due to addition of retrorockets to the vehicles.

** Reference to NASA Work Statement.

4) System reliability will be estimated using the failure rates and a functional diagram of the system.

5) System and subsystem designs will be evaluated to determine the probability of achieving the reliability goals.

6) Testing programs will be conducted on sub-scale and full-scale parts, components, subsystems, and systems as a means to verify and improve the design but not to demonstrate the reliability of the system.

Table IX-7 was constructed to show the number of full-scale tests that must be conducted in order to demonstrate a reliability of 90 percent, with confidence levels of 50, 70, and 90 percent, when 0, 1, 2, 3, 4 and 5 failures are observed during the tests.

Table IX-7

CONFIDENCE TESTING REQUIREMENTS

(For 90-percent Reliability)

Observed Number of Failures	Required Number of Full-Scale Flight Tests		
	Confidence Level		
	50%	70%	90%
0	7	12	23
1	17	25	39
2	27	37	53
3	37	47	65
4	46	58	78
5	56	70	92

It is apparent from Table IX-7 that testing to demonstrate reliability with a high confidence level requires numerous tests. Such a program is probably not economically feasible particularly if many failures are experienced.

5. BACKGROUND DATA

REVIEW OF RELIABILITY DATA

Reliability data used in Phase I, and for other studies of missiles and space boosters, were reviewed and brought up to date. These data, which include static and flight engine tests and complete flight vehicle tests for vehicles ranging in size and type of propulsion from the Falcon to the Titan are contained in the Appendix document. This information was used to develop trends and to estimate booster reliabilities.

Little data exists for large solid rocket-propulsion units comparable in size or design to the units used in this study. Although Aerojet-General and United Technology have successfully fired segmented motors on the order of 100 inches in diameter (approximately 500,000 pounds of thrust), data is still too sparse to provide conclusive reliability data. However, such tests are significant in that they demonstrate the feasibility of very large solid-propellant rocket units.

In the development of large liquid engines, Rocketdyne has successfully fired the F-1 LO_2/RP-1 propellant engine of approximately 1,500,000 pounds of thrust. Because large LO_2/LH_2 engines such as the ones under consideration in this study have not yet been tested, it is too early to attempt to derive specific implications for the reliability of the liquid stages.

The modes of failure for a number of boosters with both solid and liquid propulsion units are tabulated in the Appendix document. These data are primarily for missile boosters. Titan, Atlas, Jupiter, and Redstone liquid boosters are included. Polaris, Minuteman, and Bomarc are shown for the solid boosters. Analytical data are shown for Saturn C-1.

OBSERVED RELIABILITY GROWTH

The prediction of reliability growth in an untried system should be based on the past experience of comparable systems. However, such factors as advancements in technology and unique design features for which data are not available must also be accounted for.

In this study, the first step of the reliability program was to analyze the historical data for trends between system reliability and variables such as development activity—perhaps measured by number of tests conducted or development time.

Figure IX-6 shows a typical reliability history for solid rocket-propelled vehicles. The curve shows the cumulative ratio of successes to total test attempts, as a function of calendar year, in the flight test program of the Polaris. If the success ratio is equated with reliability, this particular system shows an erratic trend early in the program followed by a fairly steady level of reliability. This later stability indicates that the system has reached or is approaching some ultimate limit inherent in its design.

The shape of the success-ratio curve, particularly in the early stages of the development program, may vary considerably from that shown in Figure IX-6. Some of the many factors operating throughout the program which may cause this erratic behavior are: (1) the early flights may not have operational hardware; (2) tests may be made with incomplete systems; and (3) the tests may be conducted with highly skilled and technically capable personnel. Other factors which later affect the program are: (1) lower skilled personnel may be conducting the tests; (2) operational hardware may be used; and (3) the environments may become more demanding on the system and thereby affect the success of the tests, etc. Also, because later generation systems have the benefit of the technology acquired in earlier systems, they start out at a relatively more mature level of design and thus with fewer "bugs" to be eliminated in the initial test.

Figure IX-7 shows the flight test history of the Pershing missile. Here the success ratio shows a high initial value, due somewhat to statistical fluctuation. The trend after the initial stage of the development program is toward some lower level of reliability. This lower level, which is considerably higher than the level attained by Polaris, could be the result of technology acquired on earlier systems. Although the trend indicates a fairly high ultimate reliability, the sample is as yet too small to be conclusive.

6. METHOD OF ANALYSIS

The reliability analysis was a four-step process. First, each stage of a baseline booster was divided into subsystems. Second, these subsystems were assigned

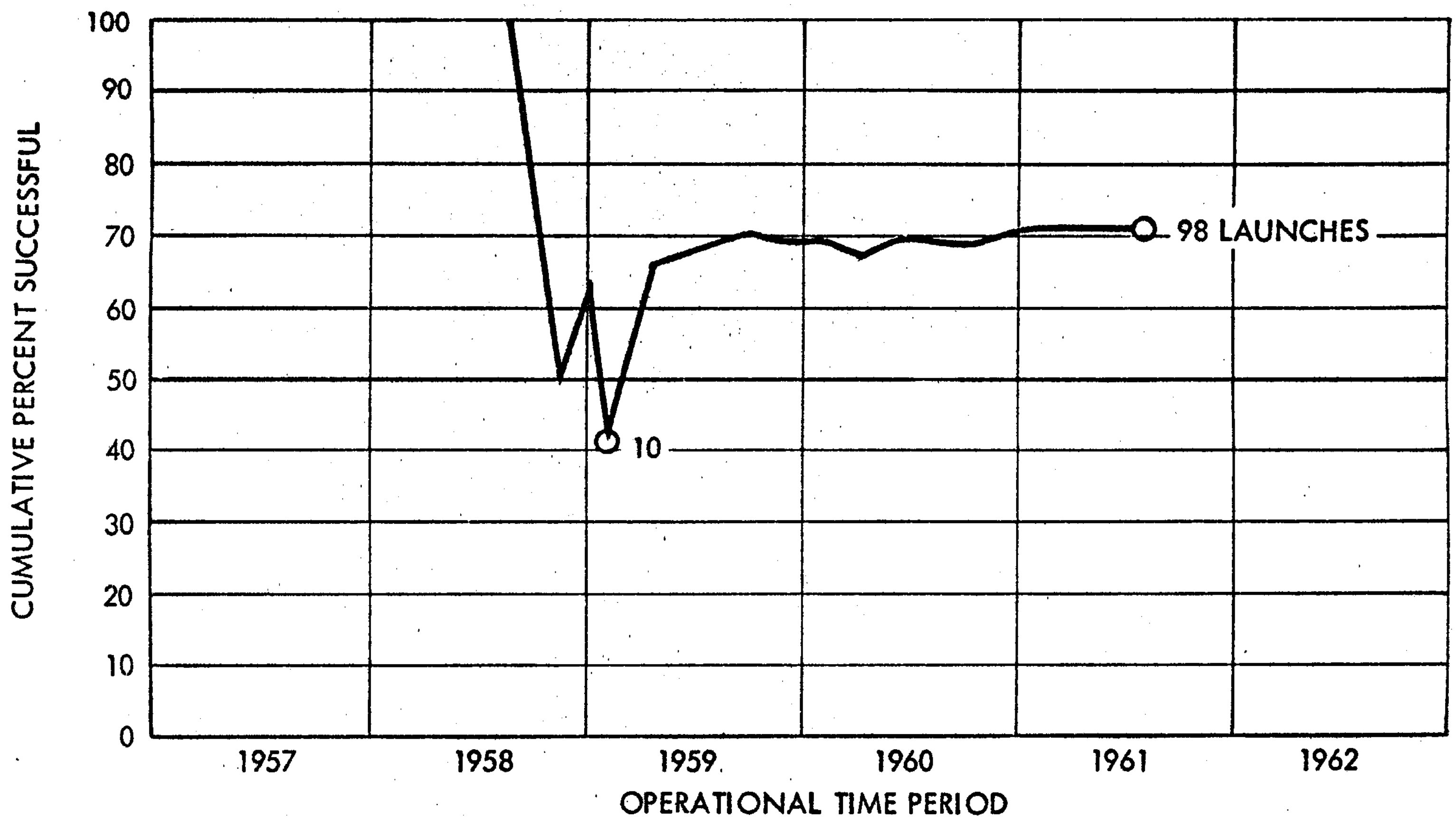


Fig. IX-6 CUMULATIVE RELIABILITY GROWTH OF POLARIS VEHICLE

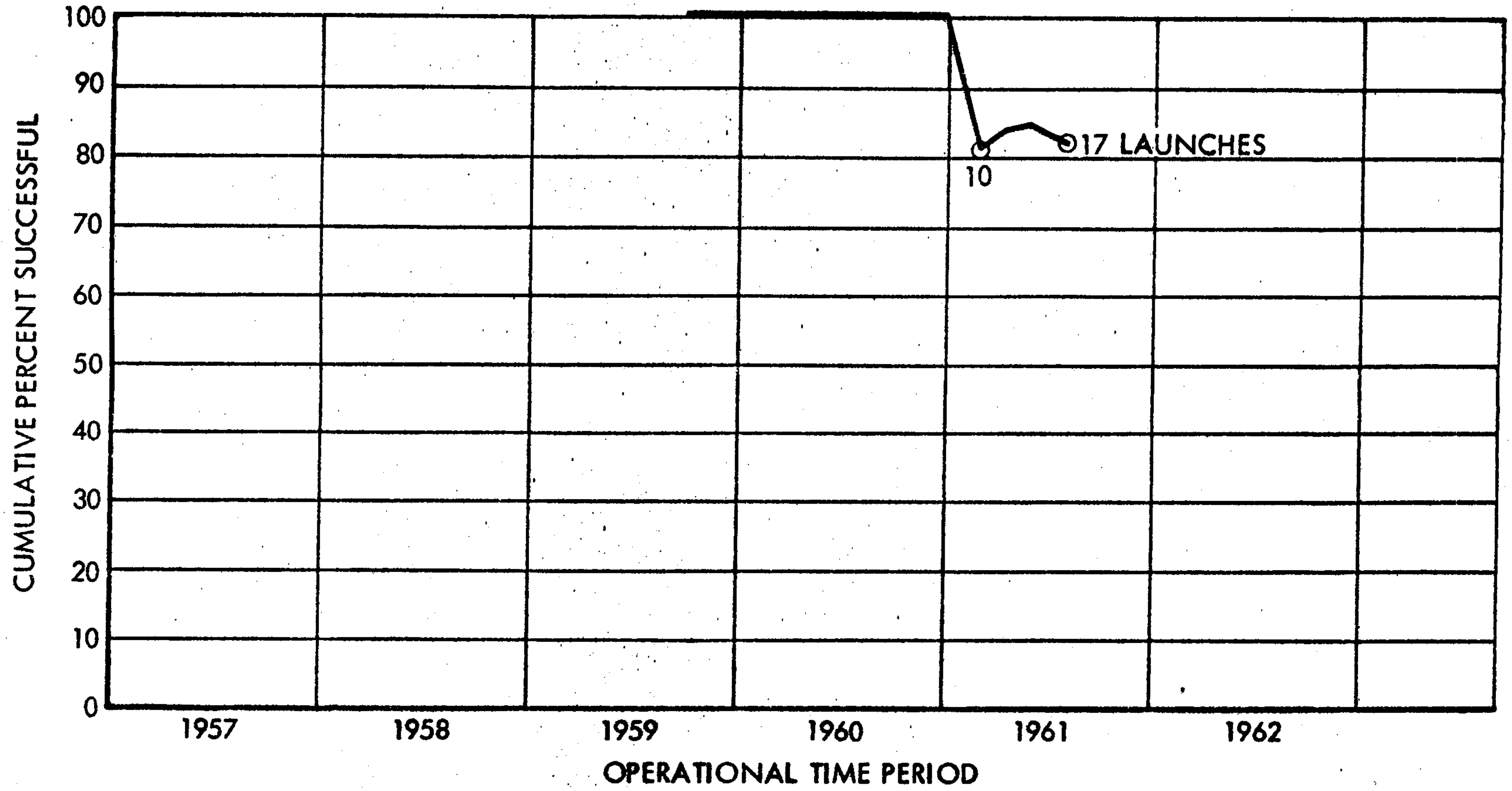


Fig. IX-7 CUMULATIVE RELIABILITY GROWTH OF PERSHING VEHICLE reliability values, based on historical data, to be used as a starting point to develop the estimates for the six study configurations. Third, the configuration estimates were used as a basis for predicting reliability growth. Fourth, problem areas revealed by the reliability estimates were investigated.

DETERMINATION OF MODES OF FAILURE

The probability of a failure is partially a function of the number of components in the system that must operate if the flight is to be successful. The major components which must operate in a solid propellant first stage booster are tabulated below.

1) Propellant
2) Case-liner internal insulation system
    a) case
    b) case liner and bonding
    c) insulation and bonding
3) Thrust-vector control system
    a) liquid storage tanks
    b) pressurization system
    c) electrical or mechanical control system
    d) valves
    e) fluid lines
4) Nozzles
5) Propellant charge ignition system
    a) propellant charge
    b) igniter assembly
        (1) squibs
        (2) lead wires
        (3) igniter case

6) Malfunction detection system
    a) pressure transducers
    b) controls
    c) accelerometers, etc.
7) Stage Guidance
    a) stability augmentation controls

Although the ignition system is listed as a reliability critical major component, it does not affect flight reliability—if it fails the mission is aborted.

The major components which must operate in a liquid-propellant second-stage booster are listed below.

1) Thrust chamber
2) Nozzle
3) Thrust-vector control system
    a) actuators
    b) servo
    c) electrical or hydraulic control system
    d) gimbals
4) Propellant feed system
    a) injector
    b) Fuel and oxidizer valves
    c) turbopump assembly
        (1) oxidizer pump
        (2) fuel pump
        (3) gear box
        (4) turbine
    d) gas generator assembly
        (1) igniter
        (2) combustion chamber
        (3) injector
        (4) valves and regulator

e) plumbing—hydraulic and pneumatic

f) electrical system

(1) throttling controls

(2) circuitry

g) heat exchangers

5) Ignition System

a) pressure tanks

b) auxiliary propellant tanks

c) regulators

d) igniters

e) ignition—detector devices

f) plumbing circuitry

6) Stage Guidance

a) stability augmentation

b) rate gyros and accelerometers

7) Malfunction detection system

a) pressure transducers

b) temperature transducers

8) Pressurization System

It is apparent from the foregoing listings that the number of major components in a liquid-propellant rocket engine is considerably higher than in a solid-propellant. Therefore, with comparable development efforts, the potential reliability of the first stage of the study vehicles is expected to be higher than the second stage.

DISTRIBUTION OF RELIABILITY

Based on an analysis of historical static and flight reliability data, supplemented by additional data from various Boeing sources (see Appendix I), a set of subsystem reliability estimates has been compiled as a basis for evaluation of the study configurations. There are many areas where the necessary background of reliability experience does not exist or was not available; for example, liquid injection thrust vector control systems for solid stages and the use of liquid hydrogen for liquid stages.

Basic differences exist between missile systems and the configurations used in this study; these differences had an influence on the reliability estimates. Higher structural safety factors and the installation of malfunction detection systems for space boosters are characteristic of these differences.

The subsystem reliability estimates used in this study are contained in Table IX-8. Three levels of reliability are shown for the first flight for each subsystem. These levels represent reliabilities which may be achieved by changing development effort for the most part; even the lower values represent somewhat higher values than have been demonstrated by past experience. The medium level will require substantial improvement over the past values and the higher level represents values that seem likely to be beyond reach within the anticipated time schedule of this program. These estimates show a wide range from the low to the high level for both the solid and liquid stage. This is a consequence of compounding the subsystem reliabilities in such a large and complex system. The values in Table IX-8 were used as a basis for evaluating the study configurations.

Table IX-8

SUBSYSTEM RELIABILITY ESTIMATES*

Stage One	Low	Medium	High
Propulsion	0.950	0.990	0.995
Thrust Vector Control	0.950	0.970	0.990
Stage Guidance and Control	0.980	0.990	0.995
Structure/Separation	0.990	0.995	0.999
Ignition	1.000	1.000	1.000
Instrumentation	0.990	0.995	1.000
Retrorocket	0.990	0.995	0.999
Human Factor	0.990	0.999	1.000
Stage Total	0.849	0.935	0.978

* These values are lower than previously reported in D2-13029 due to the addition of retrorockets to the vehicles.

Table IX-8 (Cont)

SUBSYSTEM RELIABILITY ESTIMATES

Stage Two	Low	Medium	High
Propulsion	0.855	0.930	0.980
Thrust Vector Control	0.906	0.950	0.990
Stage Guidance and Controls	0.950	0.977	0.990
Structure/Separation	0.985	0.993	0.999
Ignition	0.980	0.990	0.999
Instrumentation	0.972	0.990	0.999
Propellant Feed	0.950	0.975	0.995
Pressurization	0.980	0.990	0.999
Retrorocket	0.990	0.995	0.999
Ullage Rocket	0.990	0.995	0.999
Human Factor	0.950	0.985	1.000
Stage Total	0.599	0.791	0.950

RELIABILITY GROWTH

It is desirable to examine a number of historical records such as shown in Figures IX-6 and IX-7 to attempt to extract general trends. As a basis for such a study, the following empirical three-parameter equation is used for correlation with the observed data.

$$R = Ru \left[1 - e^{-k(a + a_o)} \right] \qquad \text{Equation (1)}$$

where:

- R = Observed cumulative ratio of successes to attempts during any stage of the development programs.
- Ru = The ultimate reliability of the system toward which R approaches as a limit when the number of tests becomes indefinitely large.
- a = The number of flight tests conducted or the number of static firings (when propulsion alone is under study).
- a_o = Parameter of the system that measures the amount of applicable past experience from which the system has benefited at the start of the program.
- k = Reliability growth rate which is indicative of the speed at which the system approaches its ultimate reliability as the program progresses.

In the model represented by the above equation, R is the dependent variable, a is the independent variable, Ru, a_o and k are parameters that depend on the nature of the system under development. By fitting available data from a number of systems, it was possible to derive general trends between different systems, as reflected in the values of the three parameters. These empirical observations then formed the basis for predicting the values of these same parameters for the study configurations.

APPLICATION OF REDUNDANCY

A simplified model was developed in previous Boeing studies to investigate the value of applying redundancy theory as a means of achieving reliability in clustered liquid-engine stages. Two factors are significant to redundancy theory.

1) Redundancy theory is primarily of value in overcoming certain types of failures (e.g. loss of thrust or pressure). It adds to unreliability where the failures are catastrophic in nature (e.g. explosion, etc.).
2) Clustering involves only one portion of the total system—guidance, flight control electronics, structure, etc. are not involved. Knowledge of the distribution of failures according to booster subsystem before applying redundancy theory is essential (e.g., spare thrust is completely ineffective in overcoming structural break-up or complete loss of guidance).

Consider a booster composed of a cluster of N propulsion units plus other necessary subsystems. System success requires N - n units of propulsion (n units of redundancy). System success is then defined by: (1) no catastrophic failure; and (2) less than or equal to n noncatastrophic failures; (3) success of other subsystems.

The following mathematical relationship can be used to calculate the booster reliability (R).

$$R = \sum_{r=o}^{n} \frac{N!}{r!\,(N-r)!} \; Pc^{o} \; Pnc^{r} \; (1 - Pc - Pnc)^{N-r} \; (P_{s2})$$

Equation (2)

Where:

Pc	=	Probability of a catastrophic failure
Pnc	=	Probability of a noncatastrophic failure
P_{s2}	=	Probability of success for nonredundant subsystems
n	=	The number of redundant units
r	=	The number of failures

Equation (2) was developed to be used in evaluating the effect of redundancy in the liquid stages of the study configurations.

B. CREW SAFETY

Crew safety is a function of the reliability of the complete launch system (i.e., launch complex, booster vehicle, and spacecraft vehicle reliabilities). This study is primarily concerned with the effect of booster design and reliability on crew safety. It is felt that detail design analyses must be made of the booster and escape system during the preliminary-design phase to ensure crew safety. Detail design analyses will also be necessary to ensure compatibility of the booster vehicle to the space-craft vehicle.

Design parameters that affect safety are: acceleration; dynamic pressure; structural safety factor; warning and escape time; and booster reliability.

1. ACCELERATIONS

An acceleration limit of 8 g's was assumed for the normal boost phase. The 8-g limit allows the crew to perform physical functions, such as operating flight controls, during the boost phase.

Under emergency conditions, the initial escape acceleration limit was set at 20 g's. This limitation is a structural limitation and not a crew limitation. The crew cannot withstand these high accelerations for more than five seconds or perform physical functions. Under extreme emergency conditions, the crew can withstand higher than 20-g accelerations. The 20-g limit provides a minimum of 12 g's to be used for separating the escape vehicle from the booster.

2. DYNAMIC PRESSURE

A maximum dynamic-pressure limit of 1200 psf was assumed for the vehicle designs. The maximum q limit was assumed to be 400 psf at stage separation.

3. STRUCTURE SAFETY FACTOR

The structure safety factor was assumed to be a 1.4 ultimate and a 1.1 yield.

4. WARNING AND ESCAPE TIME

A detailed description of the space and escape vehicle was not available. Therefore, detailed studies were not made of the warning and escape times needed for safe escape of the crew. Failures or impending failures will be detected and the escape system will be actuated by a malfunction-detection system.

The malfunction-detection system in the first stage is limited by the places and functions that can be monitored. Analyses of historical test data indicate that most solid-motor failures result in rupture and burn-through of the motor case. A rise in pressure usually provides the first indication of this type of failure. Therefore, monitoring of chamber pressure appears to be a primary requirement for each solid motor. Other areas within the motor will be monitored to measure acceleration, vibration, etc., as a further indication of incipient failures.

The second-stage malfunction-detection system was assumed to be more complex than the first-stage system. The second-stage system will have to monitor all the variables mentioned for the first stage in addition to fuel flows, combustion temperatures, turbine speeds, etc. To obtain the maximum safety from the malfunction-detection system, it will probably be necessary to design for engine-shutdown capability. This design would permit an engine to be shut down when indications are received of an impending failure in that engine, providing increased time for escape.

5. BOOSTER RELIABILITY

The effect of booster reliability on crew safety is demonstrated by the use of the following mathematical model:

$$P_S = P_B \cdot P_R + (1 - P_B)\, P_E \cdot P_{Re} \qquad (3)$$

where:

P_S = Probability of safe return for the crew

P_B = Probability of successful boost (booster reliability)

P_R = Probability of safe re-entry and return of the re-entry vehicle

P_{Re} = Probability of safe recovery of the escape vehicle

P_E = Probability of successful escape

The probability of successful boost (P_B) is the probability that the booster systems will function within prescribed limits from ignition to burnout of the final stage. The probability of safe re-entry and return includes all of the flight regime from booster burnout to landing at a designated site. The probability of safe escape is the probability that the escape vehicle will function within prescribed limits from initiation of the escape system to the required separation distance from the booster. The probability of safe recovery is the probability that, upon completion of successful escape, the vehicle can be returned to Earth and the crew recovered safely.

Figure IX-8 was computed using Equation 3 to show the effect of varying P_B and P_E on the probability of safe return. In this figure, P_{Re} was arbitrarily assigned a value of 100 percent and P_R a value of 95 percent. The probability of successful boost (P_B) was varied from 0 to 100 percent when P_E is assigned values of 80, 90, 95 and 99 percent. For a recovery probability of 100 percent, the curve shows that, when the probability of safe escape (P_E) is higher than the probability of safe re-entry (P_R), the probability of safe return of the crew (P_S) is better for low booster reliability (P_B); that is, the crew will have a higher probability for returning safely if the booster fails than if they must risk the re-entry environment.

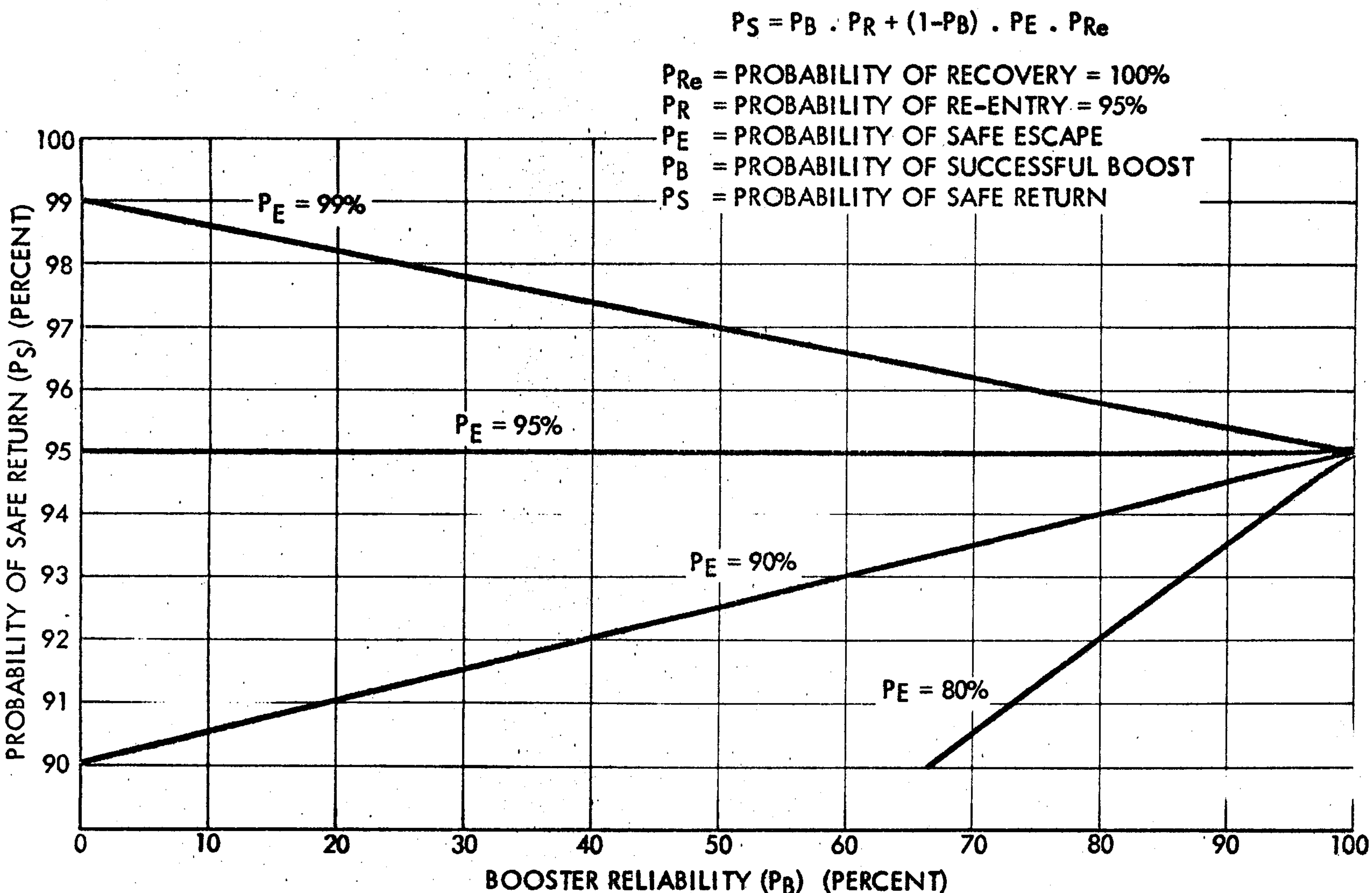


Fig. IX-8 PROBABILITY OF SAFE RETURN VS. BOOSTER RELIABILITY

A probability of recovery of 100 percent did not appear realistic for several reasons. Escapes near burnout velocity will present problems as severe as those during re-entry. The vehicle will not be landing at a prearranged site. Escape operation may jeopardize provisions for sustaining the crew after landing while awaiting pickup, etc. Figure IX-9 was plotted to show the effect of a lower probability of safe recovery (P_{Re}). A value of 95 percent was assigned, which is the same as the value assigned for probability of re-entry. The highest probability of safe return occurs for the highest value of P_E and P_B.

Based on the preceding discussions it can be concluded that, with a highly reliable escape and recovery system, the booster reliability does not have a great effect on crew safety. Thus, if the return of the flight crew is more important than successful completion of the mission, it will be necessary to place emphasis on the reliability of the escape system. A high reliability for the escape system may be easier to achieve than a high reliability for the booster system. However, it must be realized that a program has no value if the booster always fails, even though the crews are returned safely. Therefore, it is necessary to attempt to achieve relatively high booster reliabilities.

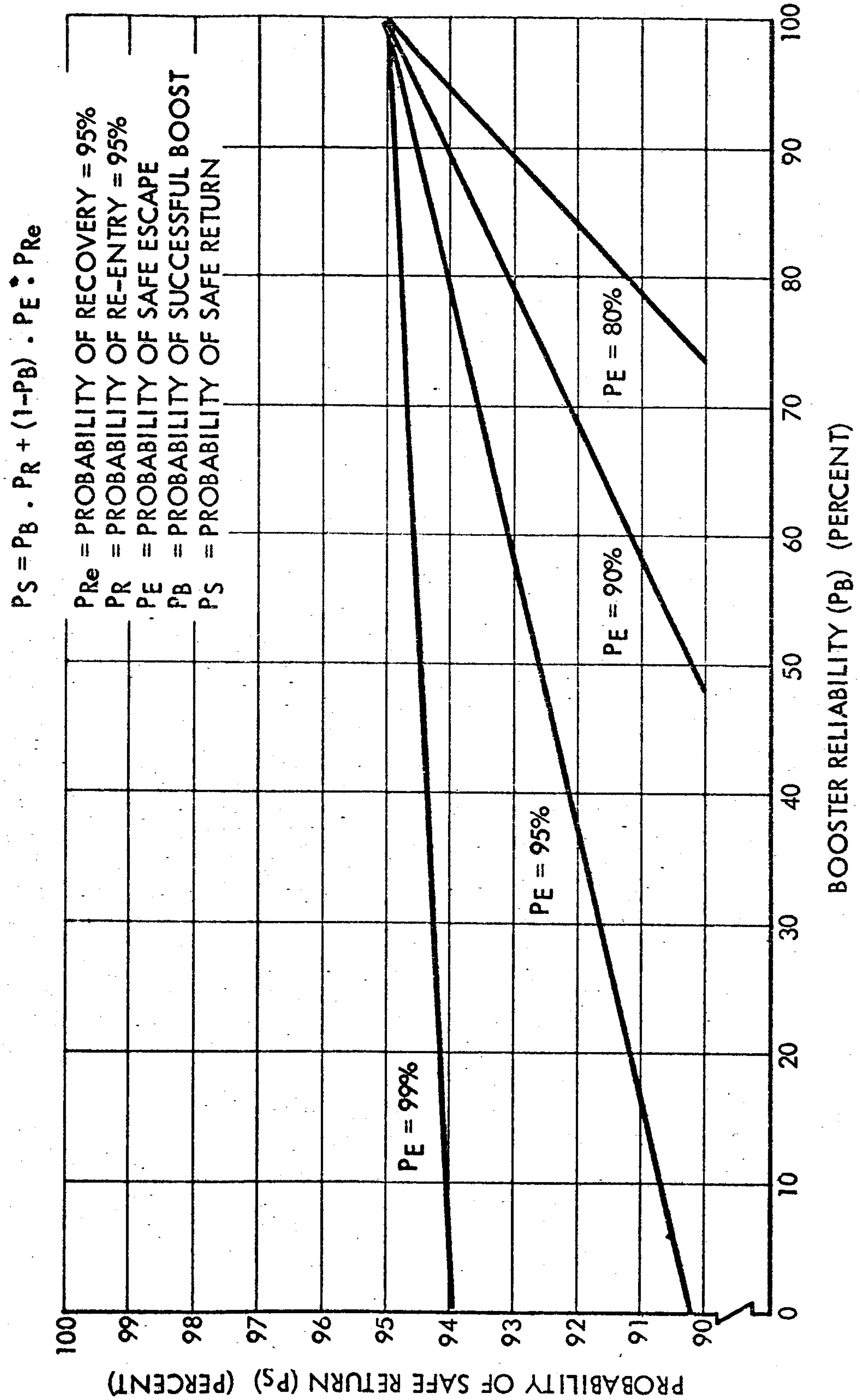


Fig. IX-9 PROBABILITY OF SAFE RETURN VS. BOOSTER RELIABILITY

X. R&D AND OPERATIONAL PROBLEMS

A. INTRODUCTION

Important in the study of large launch vehicles and their systems is the establishment of approaches and scheduling that permit good planning in terms of distribution of level of effort, time, and funding. Where problems arise, they must be defined to show their effect on planning in terms of time, cost, and technical risk. One type of problem requires only further analysis to obtain a good solution. Another type of problem is one that is not clearly understood and could have serious impact on launch vehicle programs. Problem areas defined as a result of this study are presented with proposals for their solution or study.

B. PROBLEMS REQUIRING FURTHER ANALYSIS FOR SATISFACTORY SOLUTION

1. CLUSTERING STRUCTURE

The clustering of solid motors presents problems in stage stiffness, thrust load distribution, vehicle support, and interstage structure. Solid motors undergo a change in length and diameter during ignition and burnout caused by pressurization of the motor case. Because these dimensional changes occur independently between motors, due to variations in ignition and burning times, it is necessary to allow some degree of freedom in the clustering structure. To adequately explore and optimize various clustering structure concepts and determine critical dynamic load conditions, it is necessary to undertake extensive analytic and model testing programs.

2. VEHICLE CONFIGURATION

Solid-liquid vehicles characteristically have lower first-mode body bending frequencies than all-liquid vehicles because of basic differences in mass and length distribution. This results in a requirement that solid-liquid vehicles be short enough to increase bending frequency but long enough to keep vehicle control requirements low. Trades on configuration fineness ratio, structural stiffness, and fin size are required to optimize vehicle configuration. Because vehicle configuration imposes design limitations on many vehicle components, parallel trades in other technical areas would be essential.

3. MALFUNCTION SENSING

Solid motor malfunction sensing devices are required for man-rated vehicles. The effectiveness of various types of sensing instruments in predicting booster stage failures must be determined so that an effective payload escape can be made. An analysis of this problem should be undertaken as part of any large motor or vehicle development program; it should also include an investigation of possible causes of malfunctions and their elimination.

4. VEHICLE RELIABILITY

Low vehicle reliabilities are anticipated during the early phases of vehicle operational launch programs. Reliability studies should be undertaken to determine the effects of engine-out capability on liquid stages in terms of cost per pound of payload in orbit. Further, general trades of subsystem reliability through redundancy should be made to indicate weight, performance, and other vehicle system characteristics that can be improved or optimized in terms of vehicle system objectives. This approach could have a significant impact on vehicle development test philosophy as well as on early phases of operational launch philosophy and, therefore, may be considered as a distinct problem in terms of early planning.

5. THRUST VECTOR CONTROL

Thrust vector control requirements of solid-liquid vehicles are generally low. This permits consideration of several thrust vectoring systems. Thrust vector control systems have not been demonstrated in motors having large nozzle sizes and long burning times. Further study and development of gimballed nozzles, fluid injection, and auxiliary propulsion systems is recommended. Useful studies and trades can be made on system cost, reliability, weight, development time, and technical risk.

6. SOLID MOTOR IGNITION AND BURNOUT

Ignition and burnout pressure and thrust transients must be predicted accurately for large unitized and segmented solid motors. Knowledge of these transients and their probable distribution in clustered motor boosters is required for proper analysis of clustering structures and vehicle staging problems. Application of historical data will indicate the magnitude of variations in these transients sufficiently to permit realistic design approaches.

7. SOLID BOOSTER ASSEMBLY

The assembly of solid boosters on launch pads and subsequent transportation to the launch site should be analyzed in detail, particularly in the case where handling of large solid unitized motors is required. Problems include: methods of placing and supporting in place the individual motors of a clustered booster, the method by which the clustering structure will be attached to the motors, and mating of the booster base to the launch pad.

8. CLUSTERED MOTOR IGNITION

Ignition of clustered motors by launch-retained ignition systems requires high reliability and reproducibility. Various concepts of ignition should be evaluated to determine and optimize reliability and reproducibility through use of redundant or parallel ignition systems.

9. TRANSPORTATION

Transportation studies were based, largely, on ground rules established to provide a comparative model. Further studies should be undertaken to establish transportation economics for segments, large motors, and vehicles on a more definitive basis. Of particular significance is the possibility of locating extensive manufacturing facilities at or near the launch complex. Further studies should include a deeper look at possible trades between land and waterborne transportation.

10. SOLID PROPELLANT AND SOLID MOTOR PROCESSING

The entire propellant mixing, casting, and curing operation presents serious problems in handling and processing because of the very large distances, sizes, and weights involved. A rigorous analysis should be given to these operations with emphasis on such approaches as the desirability of continuous mixing and casting and the feasibility of casting unitized motors having the nozzle end down to eliminate the need for turning the motors over.

11. SOLID PROPELLANT AND SOLID MOTOR QUALITY ASSURANCE

The influence of casting a large number of propellant batches into a single segment or motor should make the ballistic and physical properties of the motor more uniform, although the individual batches might include a wider variation in properties than would be found in small motors. This should allow a relaxation of individual batch specifications for the propellant properties that would not compromise gross motor performance. A statistical analysis of propellant variables, as they influence motor performance and grain physical integrity, should be undertaken.

A further significant factor resulting from the incorporation of many batches into a single motor is the increased probability of including a batch that would result in an unacceptable motor. Historical data on batch rejection rates and the ability to find defective batches prior to casting is required. From such data it is possible to determine an optimum, economical-to-cast grain size. The impact of continuous mixing of propellant would be considered.

12. THE EFFECT OF SOLID MOTOR PERFORMANCE VARIATION ON VEHICLE PERFORMANCE

Performance variations in solid motors may result in some compromise to vehicle performance. The influence of motor-to-motor variation in total impulse, average thrust and burning time would influence boost velocity and staging conditions. Propellant temperature sensitivity, both physical and ballistic, may influence vehicle environmental requirements. The influence of nozzle throat erosion on motor performance may require special design considerations.

13. SYSTEMS COMPONENTS TESTING

Many components of solid boosters are very large and pose problems to integrated system environmental testing. Further studies should be undertaken to establish detailed test requirements, through vehicle checkout, for all major solid booster components.

14. MOTOR CASE MATERIAL SELECTION

The use of highly heat-treated steels for large, solid motor cases requires that they be used in their brittle fracture range. Some questions exist regarding the economic feasibility of manufacturing motor cases of this size because of potentially high reject rates. Annealed titanium may prove to be a better material choice despite its high cost. Use of fiberglass as a case material appears promising; however, the fiberglass thicknesses required present problems not clearly understood. The entire problem of solid motor case materials should be analyzed in further depth.

15. ATTENUATION OF COMMUNICATIONS BY MOTOR EXHAUST

The solid rocket exhaust plumes resulting from the types of propellant proposed in this study highly attenuate telemetry or communication signals. This makes radio transmission through the exhaust plume impossible. Use of solid retro and ullage rockets for staging could result in completely stopping communications during staging, unless the propellants and arrangements of these auxiliary rockets are considered. Arrangement and location of vehicle antennae and of down-range tracking stations may be influenced by this problem. Additional studies of exhaust plume flow and attenuation characteristics are required.

16. PREFLIGHT MOTOR TESTING

Following development of very large solid motors for use in launch vehicles, some ground qualification test program for the motors must be considered. The use of a statistical reliability demonstration test series for these large motors would be prohibitive in terms of cost and development time. The effect of the number of motors used in a stage cluster on the number of motors expended in static test should be further evaluated. A study should also be undertaken to define and evaluate more fully the purpose and value of PFRT-type testing for these very large motors. The impact of using previously developed motors in large clusters for increased payload vehicles should be considered in such a study.

C. PROBLEMS REQUIRING FURTHER DEFINITION

1. PROPELLANT GRAIN BEHAVIOR

Attempts to correlate propellant grain stress analysis with propellant physical properties have been largely unsuccessful, due to the highly complex structure and behavior of composite solid propellants. Design of new propellant configurations and establishment of their required physical properties has been empirical for the most part. The use of very large motors has imposed new conditions and designs on solid propellant grain design. This general problem presently is under intensive investigation by a number of organizations. A close monitoring and collation of such data is recommended.

2. CRITICAL GRAIN SIZE AND TEMPERATURES

There is some experimental and theoretical evidence that temperature and size limits may exist for solid propellant grains. The limits predicted are close to the curing temperatures and web thicknesses encountered in designing and manufacturing the motors proposed for large solid boosters. More experimental data on large masses of solid propellant should be obtained.